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on project:

COMPREHENSIVE AND CRITICAL LITERATURE REVIEW ON IN-  
SITU MICRO-SENSORS FOR APPLICATION IN TRIBOLOGY

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## TABLE OF CONTENTS

INTRODUCTION.....	1
SELECTED RECORDS: A. GENERAL.....	3
SELECTED RECORDS: B. PERTAINING TO MACHINERY CONDITION.....	5
ELEVEN EXAMPLES FOR DETAILED DISCUSSION.....	25
SOME CONCLUDING REMARKS.....	48
PROMISING APPROACHES/IDEAS.....	49
LITERATURE ON SENSORS.....	50

### APPENDIX

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## INTRODUCTION

This is the final technical report of the project sponsored by the Office of Naval Research, under grant No. N00014-93-1-0674, entitled Comprehensive and Critical Literature Review on In-Situ Micro-Sensors for Applications in Tribology.

Inasmuch as the literature on sensors is vast, two filters have been invoked in this survey of literature on sensors: (1) only those which might have relevance, direct or potential, to machinery condition sensing are included; (2) only those which might lend themselves to, presently or potentially, fiber-optical mode of information transmission are included. The latter filter suggested a fifteen year limit of formal search of literature, with earlier works brought in by a perceived relevance criterion. In other words, earlier references are included to complete a chain of contributions leading to a major one. It is felt that the search should be larger than a strict definition of in-situ as well as micro-sensors.

Using The University of Texas at Austin's U-Search and the Engineering Index, and augmented by several commercial data bases, 28,000 records were studied and selected records have been included for this report; each of the selected records has an abstract, either the authors' or an abridged one, and are included under LITERATURE ON SENSORS. It should be noted that literature on information processing has been screened out. The reasons are two-fold: (1) information processing technology literature is vast in its own right; (b) there are significant advances in information processing technology that would match the needs for sensor systems. In other words, it is tacitly assumed that this assessment would be more successful if not commingled with an allied but separate technology, which can be brought forth on the need basis later.

Throughout, a sensor or transducer is understood to be a device that provides a usable output in response to a specific measurand; it is understood that such devices are called different names in different fields. This project has a highly restricted scope; for general reference to sensors one of many handbooks\* may be consulted.

It might be of interest to note that, based on the human eye and the total sensing system, the sensor functions are divided into physical effect and information processing function, and the parallel development of both technologies, determines the evolution of vision and recognition. Sight is considered the most highly developed of all our senses. Self-organization and knowledge-basing are key technologies which allow a lack of knowledge or deficient sensor characteristics to be overcome. In many fields of sensor technology, evolution is now only taking place through further development of signal evaluation techniques. New areas of application, on the other hand, are not being opened up by enhanced use of software, but predominantly by revolutionary materials development\*\*.

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\* Norton, H.N., Sensors and Analyzer Handbook, Prentice Hall, 1982.

\*\* Kleinschmidt, P. and Hanrieder, W., "The Future of Sensors, Materials Science or Software Engineering," Sensors and Actuators, A33, 5-17 (1992).



In view of the fact that there are preciously few in-situ micro-sensor records formed among the 28,000 studied under this project, the selection of relevant records for the final report needs special explanation. First, earlier on in the INTRODUCTION section, mention was made of two filters which have been invoked. Second, the goal of the project concerns chemical as well as physical sensors of micro-dimension pertaining to lubricated contacts as to abrasive wear, friction, corrosive wear, cracks, micro-particle analysis, identification of surface film-formation, load, micro-particle detection, position, speed, surface damage and temperature. Third, a research need analysis was proposed in anticipation of the aforementioned fact that few sensors in this context would be in-situ, let alone being of micro-dimension.

With the above in mind, 190 records were selected. Of necessity, most were selected either because the potential of implementing an idea in-situ and of micro-dimension or because it is an illustration method in the in-situ and micro-sensors realm.

In terms of presentation, the actual records, complete with abstracts are listed at the end of the text proper under LITERATURE ON SENSORS; the reason is its relative bulkiness. The 190 records, by year, title and author, are presented first in 13 categories. These are presented in two sections, SELECTED RECORDS: A. GENERAL and SELECTED RECORDS: B. PERTAINING TO MACHINERY CONDITION. Note some of the titles are in a different and hollow font. There are 11 of those which have been selected to appear in more detailed under ELEVEN EXAMPLES FOR DETAILED DISCUSSION.

Following the above are SOME CONCLUDING REMARKS, PROMISING APPROACHES/IDEAS, and a detailed analysis of machinery condition sensing. The latter is appended to this report under APPENDIX.

**SELECTED RECORDS: A. GENERAL**

## SELECTED RECORDS - A. GENERAL

### ACCELEROMETER

- 1993 mechanical resonator monolithically integrated with laser diodes on gallium arsenide - *Ukita et al*
- 1992 smart accelerometer with on-chip electronics fabricated by a commercial CMOS process - *Riethmuller et al*
- 1992 analysis of twin-mass structure for a piezoresistive accelerometer - *Shen et al*
- 1992 piezoresistive acceleration sensor for automotive application - *Tsugai et al*
- 1991 fabrication and characterization of silicon micromachined threshold accelerometers - *Lobe et al*
- 1991 surface micromachined accelerometer - *Payne*
- 1990 piezoelectric quartz vibrating beam in a digital accelerometer - *Meldrum*
- 1987 fiber optics acceleration sensor - *Daneshvar et al*

## **ACOUSTIC EMISSION**

- 1992 intrinsic optical fibre sensor for detecting acoustic emission -  
*Zheng et al*
- 1991 ultrasonic transducers with piezoelectric polymer foil - *Harnisch et al*
- 1991 general problems of acoustic emission sensors - *Higo and Inaba*
- 1991 piezoceramics and sensor applications - *Petrucci*
- 1990 gear box failure - *Aatola and Leskinen*
- 1990 on-line ultrasonic monitoring for bearing wear - *Chann*
- 1990 detecting hydrogen assisted cracking of low alloy steel - *Hayashi*
- 1989 testing of F-111 - *Carlyle*
- 1989 Surface Acoustic Wave (SAW) sensors - *D'Amico and Verona*
- 1989 rolling element bearings - *Hawman and Galinaitis*
- 1989 wear of high speed ceramic insert - *Young and Houghton*

## **ACOUSTIC EMISSION - continued**

- 1988 grinding process - *Sarshevskii*
- 1988 incipient bearing failure by noise cancellation - *Tau*
- 1988 sensors manufacturing - *Tse and Dornfeld*
- 1987 tool fracture by acoustic emission - *Diei and Dornfeld*
- 1987 hot tearing in castings - *Ohtaki et al*
- 1987 review of acoustic emission in pressure vessels - *Tonolini et al*
- 1986 manufacturing process - *Dornfeld*
- 1986 in-process detection of grinding cracks - *Eda*
- 1986 acoustic emission in the plastic industry - *Fowler*
- 1986 status and future of acoustic emission in nuclear reactor systems -  
*Houlton*
- 1986 high fidelity transducers - *Proctor*
- 1986 in-process tool wear - *Tse*

## **ELECTRIC CONTACT RESISTANCE AND CAPACITANCE SENSING**

- 1992 Proceedings of EUROSensors V - 69 papers including capacitance-based sensors and many other types - *D'Amico, ed.*
- 1992 controlled selectivity of polysiloxane coatings: their use in capacitance sensors - *Hang et al*
- 1992 micromachined sensor structures with linear capacitive response - *Rosengren et al*
- 1992 capacitive oil deterioration sensor - *Saloka and Meitzler*
- 1987 state of oil film - *Nakashima and Takafuji*
- 1986 gear tool noise - *Atherton*
- 1986 AC impedance measurements of the resistance and capacitance of lubricant film - *Wang et al*
- 1986 new instrument for measuring electric contact resistance - *Watanabe*

## **FIBER OPTICS**

- 1993 optical sensors, fiber optic sensors - *Goure*
- 1992 Large band-width reflection fiber-optic sensors for turbomachinery rotor blade diagnostics - *Andrenelli and Rossi*
- 1992 Naval fiberoptic system development program - *Blackwell*
- 1992 long-term performance of fiber optic cable plant in Navy ships - *Brown et al*
- 1992 fiber-optic Bragg-grating differential-temperature sensor - *Kersey and Berkoff*
- 1992 evaluation of commercial fiber optic sensors in a marine boiler room - *Musselman*
- 1991 planar fiber optic acoustic sensors - *Lagakes et al*
- 1989 implementation of fibre optics in U.S. Naval combatants - *Johnston and Stewart*
- 1989 fibres are ready made sensors - *Parry*
- 1989 temperature sensors - *Schaefer*
- 1989 using fiberoptics for practical sensing - *Wohstein*

### **FIBER OPTICS - continued**

- 1988 fiber optic and laser sensors IV - *DePaula , ed. and Udd, ed.*
- 1988 fiber optic displacement sensor for detecting roller bearing condition - *Philips*
- 1987 fiber optic sensors - *Arditty et al*
- 1987 fiber optic sensors, a review - *Jackson*
- 1987 industrial sensors using laser scanning - *Jones*
- 1987 implementation of fiber optic technology in naval combatants - *Morais*
- 1987 fiber optics in machine vision - *Vinarub and Flom*
- 1987 non-contact surface flow detection by fiber optic reflection sensors - *Waegli et al*



## **FORCE AND FORCE-RELATED SENSING**

- 1992 Proceedings of EUROSensors V - 45 papers on various physical sensors including three for force measurements - *D'Amico, ed.*
- 1992 new tactile sensor like the human hand and its application - *Omata and Terunuma*
- 1992 tactile imaging; review of design problems and the state-of-art of tactile sensing - *Regtieu*
- 1992 non-contacting torque measurement by a modified moire-fringe method - *Spooner et al*
- 1992 capacitive tactile sensor for shear and normal force measurements - *Zhu and Spronck*
- 1991 dynamometrical sensors - *Bethe*
- 1991 sillon on sapphire strain gauge sensors - *Stuchebrukov*
- 1991 piezoelectrically driven silicon beam force sensor - *Van Mullen*
- 1989 fiber optic torquemeter design and development - *Rudd et al.*
- 1987 fiber optic sensor sensitive to normal pressure and shear stress - *Cuomo et al*

## **FLUID FLOW AND HEAT TRANSFER**

- 1992 optical fiber vortex sensor for flowrate measurements - *Herzog*
- 1992 liquid density sensing by using a photothermal vibration - *Inaba*
- 1992 a liquid shear stress sensor fabricated using wafer bonding technology for use in fluid environment - *Ng et al*
- 1992 monolithic flow sensor for measuring millilitre per minute liquid flow - *Yang and Soeberg*
- 1991 quartz crystal oscillator for under-liquid sensing - *Barnes*
- 1991 optical fiber flowmeter - *Herzog et al*
- 1991 prediction of contact parameters by ultrasonic methods - *Krolkowski and Szczepek*
- 1991 small single-sensor for temperature, flow and pressure measurement - *Sun and Kamal*
- 1990 microsensors using micromachining: pressure, humidity, microviscometers, thermistors, thermocouples and flowmeters - *Udell et al*

## **PRESSURE SENSING**

- 1992 design of monolithic, signal conditioned pressure sensor - *Baslett et al*
- 1992 silicon pressure sensor with integrated bias stabilization and temperature compensation - *Crazzolara et al*
- 1992 comparison between micromachined pressure sensors using quartz or silicon vibrating beams - *Dufour et al*
- 1992 silicon optical pressure sensor - *Dzinban et al*
- 1992 merging micromachining and microelectronics - *Frank*
- 1992 silicon-on-oxide pressure sensor for high temperature - *French et al*
- 1992 fabrication of microdiaphragm pressure sensor using micromachining - *Fujii et al*
- 1992 fiber optic pressure sensor - *Ingold et al*
- 1992 multiplexed piezoelectric polymer tactile sensor - *Kolesar et al*
- 1992 optically excited silicon sensor for downhole pressure monitoring - *Kristeroy et al*
- 1992 smart CMOS capacitive pressure transducers with on-chip calibration capability - *Schnatz et al*
- 1992 optical pressure sensors based on semiconductor quantum wells - *Trzeciakonoski et al*

## PRESSURE SENSING - continued

- 1992 dynamic properties of pressure sensors based on Al GaAs films  
- *Zilionis et al*
- 1991 epitaxial silicon on zirconia (502) pressure sensors - *Chen et al*
- 1991 CMOS circuit for piezoresistive pressure sensor - *Gokkestad et al*
- 1991 surface micro-machine transducers - *Guckert*
- 1991 piezoresistive pressure sensors polycrystalline silicon - *Mosser et al*
- 1991 fiber-optic diaphragm pressure sensor - *Yuan and Qiu*
- 1991 Al GaAs semiconductor pressure sensor - *Zilionis and Stanheric*
- 1990 silicon capacitive pressure transducer - *Artyomov et al*
- 1990 cold silicon piezoresistive strain gauge - *Boyd et al*
- 1990 absolute pressure silicon sensor by air-tight electrical feedthrough structure - *Esashi*
- 1990 piezoresistive low-pressure sensor - *Sandmaier and Kuehl*
- 1989 piezoelectric ceramics for contact pressure measurement - *Oda et al*
- 1983 Raman spectroscopy to measure pressure in elastohydrodynamic lubricating film - *Gardiner et al*

## VIBRATIONS AND WAVES

- 1992 elastic wave sensors-quartz technological channel and silicon technology - *Handen et al*
- 1992 pattern recognition based bicoherence analysis of vibration in bearings - *Li et al*
- 1992 characterization of a new device for pressure sensing - *Lorenzini et al*
- 1992 simple fibre optic sensor for measuring vibration frequency - *Philip et al*
- 1992 correlating vibration measurement and tool wear in turning - *Sokolowski et al*
- 1990 rolling element bearing failure detection by changes in vibration response - *Reif and Lai*
- 1988 bearing behavior by statistical analysis of vibrations - *Gudonavicius et al*
- 1988 bearing condition by vibration analysis - *Mathew and Sefredson*
- 1988 time domain analysis of vibration in bearing behavior - *Springer*
- 1987 defects of power bearing by frequency spectrum - *Ivanov*
- 1987 machinery damage - *Kuoppala and Kuusisto*
- 1987 inspection of gear box by laser vibration measurement - *Watts et al*
- 1986 non-contact surface vibration analysis using monomode fibre interferometer incorporating an open air path - *vin et al*

**SELECTED RECORDS: B. PERTAINING  
TO MACHINERY CONDITION**

**SELECTED RECORDS - B. PERTAINING TO MACHINERY CONDITION**

**CHEMICAL SENSING**

- 1993 fiber-optic photothermal interferometric sensor: a novel technique for chemical measurements - *Balconi et al*
- 1993 micromachining a miniaturized capillary electrophoresis-based chemical analysis system on a chip - *Harrison*
- 1992 mechanical resonance gas sensors with piezoelectric excitation and detection using PVDF polymer foils - *Bloch et al*
- 1992 optical and piezoelectric analysis of polymer films for chemical sensor characterization - *Bowman et al*
- 1992 Proceedings of EUROSENSORS V - 56 articles on mostly chemical and biochemical sensors - *D'Amico, ed.*
- 1992 Proceedings of EUROSENSORS V - 89 papers on chemical and electrochemical sensors - *D'Amico ed.*
- 1992 optical chemical sensor based on surface plasma on interrogation - *De Maria and Martinelli*
- 1992 gas sensor system with dielectric and mass sensors - *Endres et al*

## **CHEMICAL SENSING** - continued

- 1992 selective detection of organic molecules with polymers and supramolecular compounds - *Schierbaum et al*
- 1992 application specific design of a piezoelectric chemosensor array - *Schmantz*
- 1992 silicon integrated miniature chemical analysis system - *Van der School et al*
- 1991 diffusion of extreme pressure-antiwear additives in oil by holographic interferometry - *Dudler et al*
- 1991 calorimeter gas sensor - *Miuro et al*
- 1990 piezoelectric resonator for - *Maramatsu et al*
- 1987 oxidative stability of lubricants by chemical luminescence - *Benor and Murray*
- 1986 chemical analysis with fibre optics - *Krohn*
- 1986 sensing chemicals with optical fibres - *Narayanaswamy*
- 1979 emission microspectrophotometer for surface analysis in lubrication - *Lauer and King*



## **DISPLACEMENT STRAIN AND FILM THICKNESS SENSING**

- 1993 Bragg grating-timed fiber laser strain sensor system - *Melle et al*
- 1992 real-time holographic interferometry through fibre optics - *Dudderar and Gilbert*
- 1992 non-contact absolute position measurement using a compact disc player optical pick-up - *During et al*
- 1992 a high precision, six degree-of-freedom single-sided noncontact, optical sensor suitable for assembly automation - *Mancevski et al*
- 1992 fiber optic sensors focus on smart systems, e.g., all-fiber, intrinsic Fabry-Pecot strain sensors - *Measures and Liu*
- 1992 polycromatic birefringence sensing for optical fibre monitoring of surface strain - *Murphy and Jones*
- 1992 silicon subminiature microphone based on piezoresistive polysilicon strain gauges - *Schellin and Hess*

## **DISPLACEMENT, STRAIN AND FILM THICKNESS SENSING**

- continued

- 1991 oil film thickness between piston ring-cylinder by laser fluorescence - *Lux and Hoult*
- 1991 three-dimensional position determination - *Nashman and Karen*
- 1991 R-C oscillation technique for measuring oil film thickness in elastohydrodynamic lubrication - *Zhang et al*
- 1991 simple capacitive displacement sensor - *Zhu et al*
- 1990 angular displacement by intensity of reflected light measurement - *Partaatmadja et al*
- 1990 strain field in sliding contacts by laser speckle and metallographic techniques - *Seif et al*
- 1988 fiber optic lever displacement transducers - *Kissinger*
- 1982 laser interferometer for air bearing separation measurement - *Nigam*

## **LUBRICANT CONDITION CHARACTERIZATION**

- 1992 measuring engine oil film, using fiber optics and laser induced fluorescence - *Richardson and Borman*
- 1992 fluorescent sensor as an engine oil quality indicator - *Vinas et al*
- 1991 in-lubro studies of lubricants in EHD contacts using FTIR absorption spectroscopy - *Cann and Spikes*
- 1991 in-situ electro-charging for friction reduction and wear resistant film formation - *Tung and Wang*
- 1990 analysis of lubricant oxidation products by digital imaging processing techniques - *Schilowitz et al*
- 1989 shear in elastohydrodynamic contacts - *Cann and Spikes*
- 1987 in-situ SEM study of boundary lubricated contacts - *Holzhauser and Ling*
- 1987 coolant contamination of lubricating oil using radioisotope
- 1985 advanced mass spectrometry - *Campana and Freas*

## **SURFACE TEMPERATURE SENSING**

- 1993 quartz crystal socillator used as temperature sensor - *Azcondo and Peire*
- 1992 wavelenght-demultiplexed fiber-optic temperature measurement instrument - *Andrew et al*
- 1992 pure and calcium-modified lead titanate ceramics for pyroelectric sensors de Frutos and Jiminez
- 1992 high speed sensitive thermovoltaic IR detectors - *Marchetti and Simili*
- 1992 all-fibre optically addressed silicon microresonator sensor for pressure and temperature measurements - *Rao et al*
- 1992 thin film thermocouple for contact temperature measurement - *Tian et al*
- 1992 effect of process parameter variation on polysilicon temperature transducer characteristics - *Zucker et al*
- 1991 in-process workpiece temperature - *Cogdell*
- 1989 thin film thermopile detector - *Hamel*
- 1989 fibre-optic and quartz sensors - *Schaefer*
- 1988 infrared technique in EHD contacts - *Hou*
- 1988 bearing defects by pattern recognition analysis of vibrations - *Li*
- 1986 temperature measurement in subsurface layer - *Ko*

## **WEAR AND BEARING DAMAGE SENSING**

- 1992 ferrographic analysis of failure process in journal bearing -  
*Akagaki and Kato*
- 1992 dynamic wear tests in the SEM - *Calabrese et al*
- 1992 initial fault detection of a tapered roller bearing - *Su and Lin*
- 1991 adhesive and abrasive wear - *Boness and McBride*
- 1991 wear processes by acoustic emission - *Hanchi and Klawecki*
- 1991 automated image analysis for study of wear particles in oil-lubricated systems - *Uedelhoven and Guttenberger*
- 1990 in-situ friction and wear measurement in integrated polysilicon mechanisms - *Gabriel et al*
- 1990 on-line tribology measurements on lubricated rigid disks -  
*Nunnelley et al*
- 1990 on-line tool wear sensing by pneumatic sensor - *Sanjanwala et al*

**WEAR AND BEARING DAMAGE SENSING - continued**

- 1988 antifriction bearing fault detection - *Burgess*
- 1988 complete oil breakdown rate analyzer (COBRA) and quantitative debris monitor (QDM) - *Centers and Price*
- 1988 Quantimet in thin-film lubrication wear and galling of aircraft fuel pump shafts and gears by surface activation techniques - *Gallmann et al*
- 1988 on-line severity assessment of bearing damage - *Li and Wu*
- 1988 in-situ friction/wear/electrical contact resistance in scanning Auger microprobe - *Pope and Peebles*
- 1987 machinery faults - *Lim*
- 1987 ferrography in conjunction with - *Roylance and Vaughan*
- 1986 process on the basis of wear particles - *Barwell*
- 1972 wear particles in lubricating oils - *Seifert and Westcott*

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## **ELEVEN EXAMPLES FOR DETAILED DISCUSSION**



### **Mechanical Resonator Monolithically Integrated with Laser Diodes on GaAs**

Ukita, Umishi and Tanaka (1993) made a microdevice shown in Fig. 1. Gallium arsenide was used in order to integrate optical and mechanical structures. Of course, silicon wafer does not lend itself to integrate light source with si-based micromechanical structures. It is to be noted that optical methods do not interfere with electromagnetic environments.

The microbeam (MB) shown is only 5  $\mu\text{m}$  in depth. The short distance between the laser diodes ( $\text{LD}_1$  and  $\text{LD}_2$ ) and MB does not require lenses to make the light beam converge. Pulsed  $\text{LD}_2$  causes resonant frequency of MB;  $\text{LD}_1$  and the photodiode detect vibration, excited by thermal stress. In another term, micromechanical filters for optical signal processing and pick-ups for optical recording are used. The system can be used as an accelerometer and like systems can be adapted for other sensing applications.

Ukita et al (1993):

MECHANICAL RESONATOR MONOLITHICALLY  
INTEGRATED WITH LASER DIODES ON GaAs

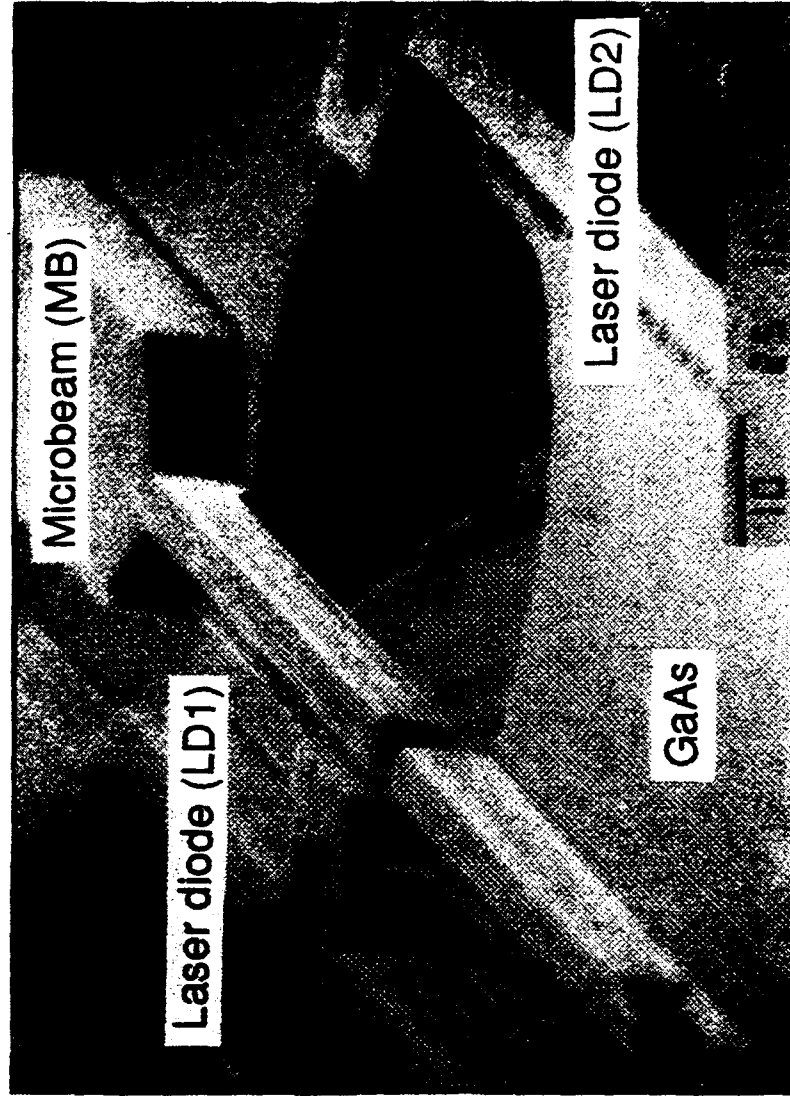


FIG. 1

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## **On-Line Ultrasonic Monitoring of Bearing Wear**

Chann (1990) reported an ultrasonic technique for bearing wear monitoring which measures material loss from the bearing surface. The system tracks this wear from inception through the point of bearing instability.

Fig. 2 shows a sequence of pictures. From top to bottom the pictures denote the following: First, the ultrasonic transducer is mounted in the bearing in such a way that it becomes an integral part of the bearing. Second, a piezoelectric crystal is located within the transducer. Third, the crystal emits a high frequency sound wave when it is excited by a signal from the monitoring system; the signal travels to the face of the transducers and echoes back. Fourth, the echo of the signal re-excites the crystal; a signal then travels from the excited crystal back to the electronic system. Fifth, the electronic system measures the time from signal emission to the receipt of the echo; this is translated to the distance measured and therefore wear when compared with the original distance.

Chann (1990):

ON-LINE ULTRASONIC MONITORING  
OF BEARING WEAR

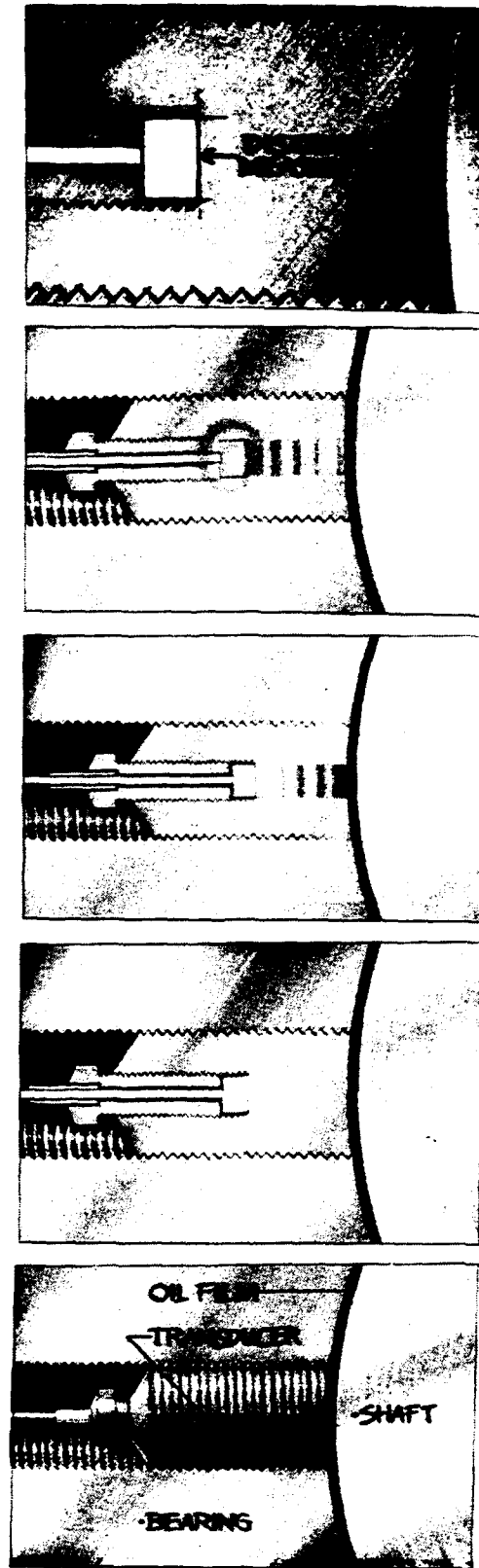


FIG. 2

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### **Capacitive Tactile Sensor for Shear and Normal Force Measurement**

Zhu and Spronck (1992) devised a sensor for shear as well as normal force measurement, using parallel-plate capacitor with Kelvin guarding, i.e., small displacements in the x and z direction would change the capacitance. See Fig. 3 for the basic parallel plate system on the left.

The actual system is shown schematically on the right. This is a cross-sectional view of the tactile sensor, showing the reference electrodes (three strips and eight electrodes of the sampling array.) The whole assembly is covered by a silicon rubber skin.

In terms of operation, shear and normal forces are determined by measuring variation in the phase and amplitude of the output signal, respectively. Through analytical expressions which relate the variables, the forces can be resolved. Experimental model of the sensor shows a resolution of 0.05 N over the range of 10 N for both shear and normal force measurements.

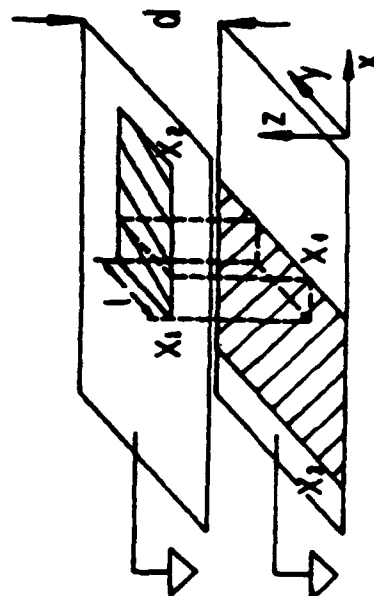
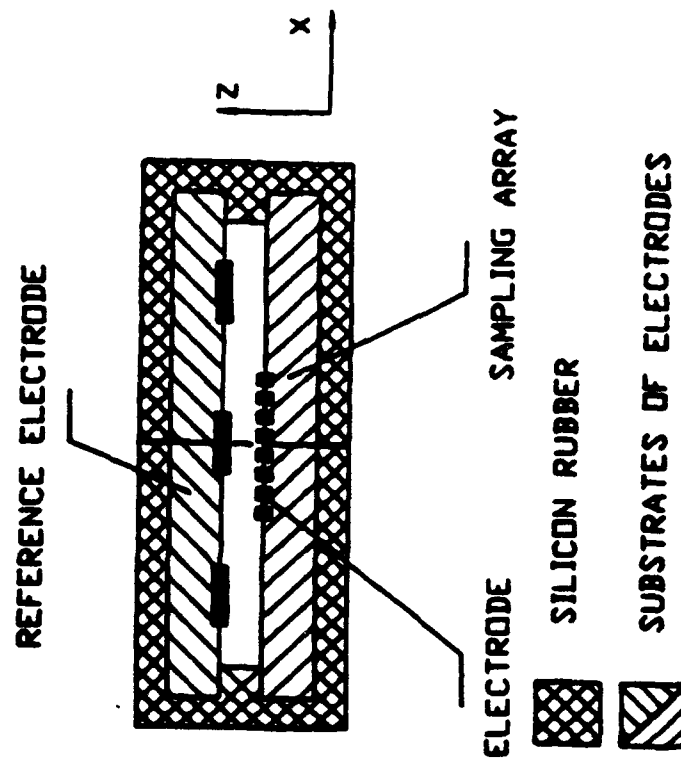


FIG. 3

## **Fiber Optic Pressure Sensor**

Ingold, Sun and Bigelow (1991) highlighted the efforts of the Naval Surface Warfare Center to develop a fiber optic pressure transducer. The requirements are a 90-100 p.s.i. gage sensor which can sustain a high-shock, shipboard environment.

Fig. 4 shows schematically the sensor system. Signal conditioning is done away from the actual sensor; of course, fiber optic transmission is used. The conditioner can be placed for ease of repair.

For a robust system, a Bourdon tube mechanism, to which quartz crystal is attached, is used. These mechanisms allow the pressure to be converted into a longitudinal force that is applied evenly and accurately to the quartz crystal. Optical powering and interrogation of the quartz crystal allows the sensor to be completely, electrically isolated from the signal conditioner. All information and power is transferred via a single optical fiber.

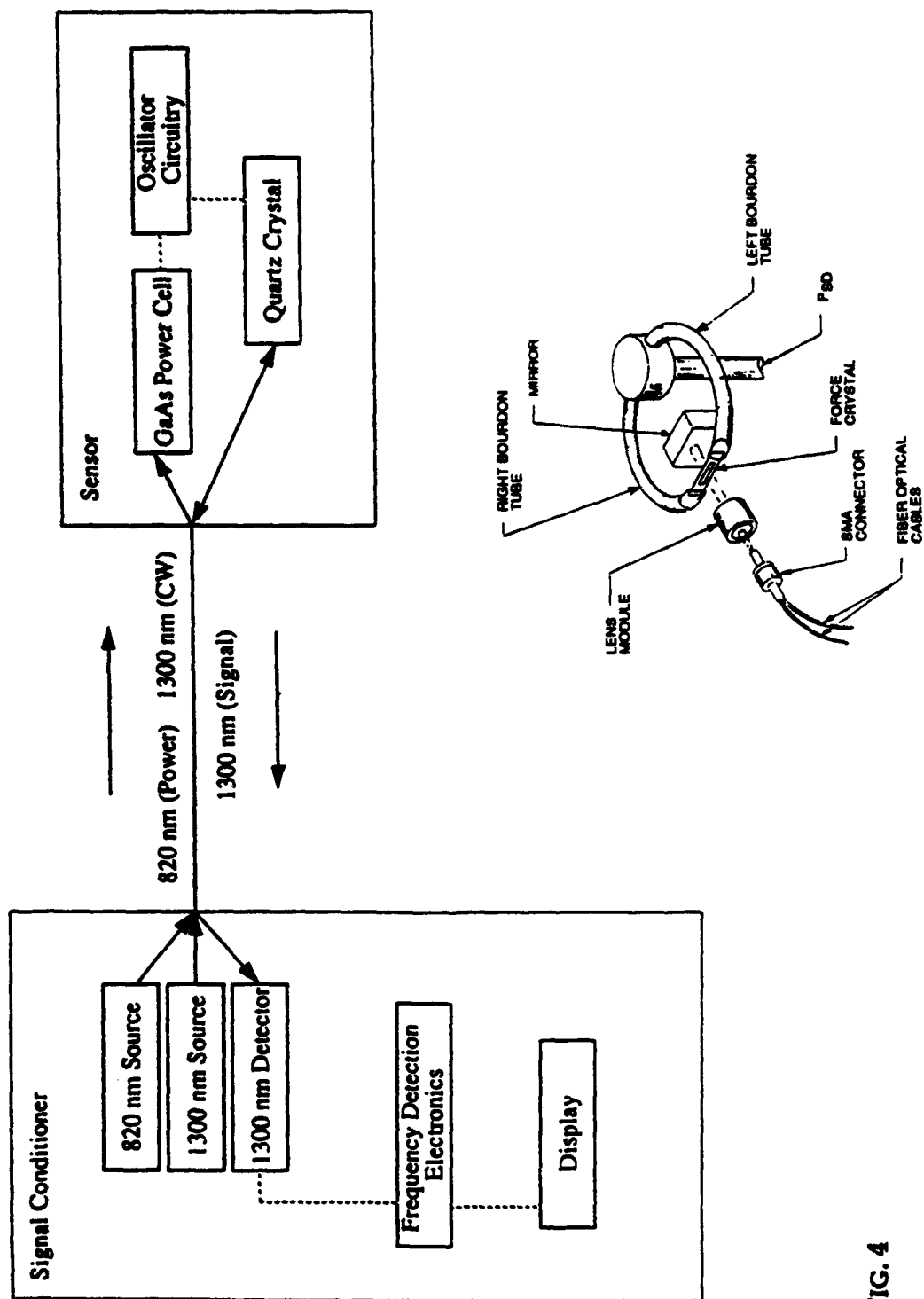


FIG. 4



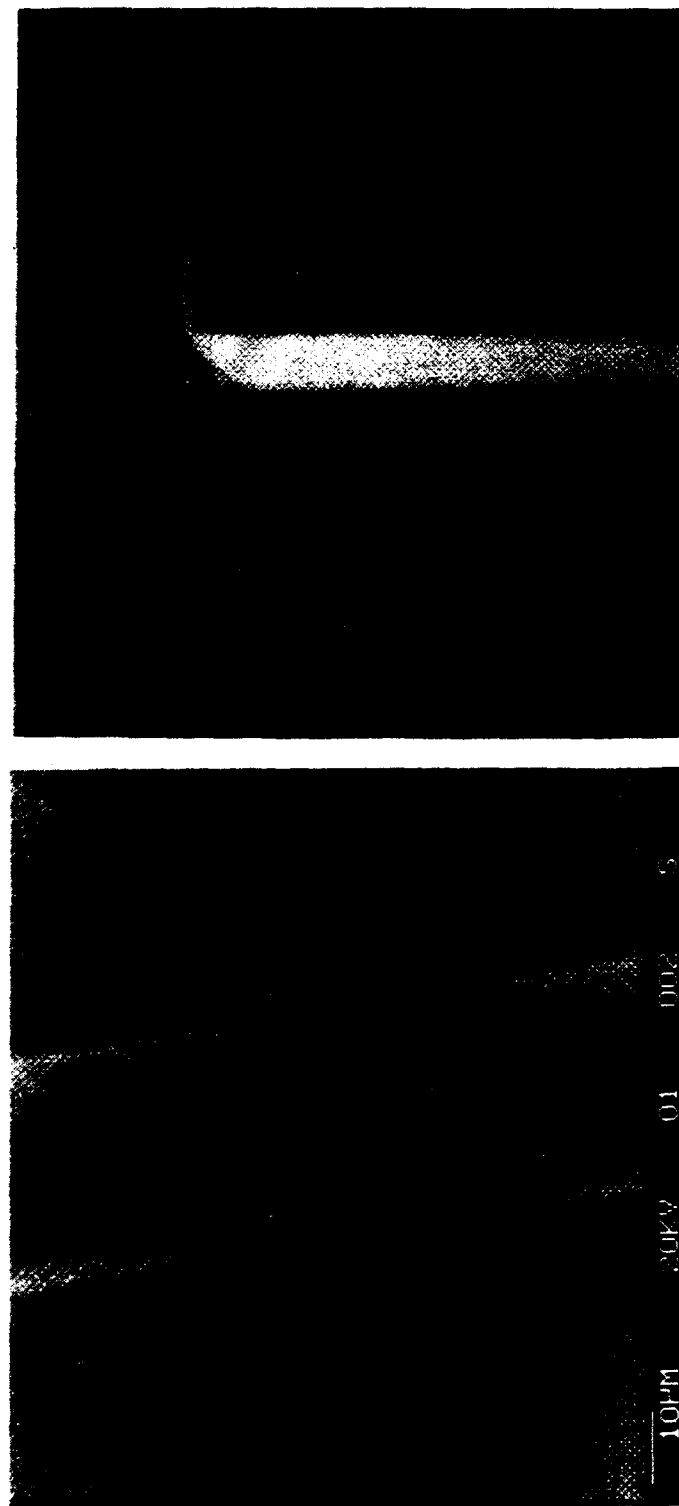
### **Micromachining A Miniaturized Capillary Electrophoresis-Based Chemical Analysis System on A Chip.**

Harrison, Fluri, Seiler, Fan, Effenhauser, and Manz (1993) reported their work, using photolithography and chemical etching techniques. These techniques have been combined to create the field of micromachining in which 3-dimensional-microstructures such as motors, tweezers, beams, pumps and valves have been fabricated. The use of micromachining to fabricate chemical sensors, chemical analysis systems and such is still in its infancy.

This report, see Fig. 5, is concerned with the integration of several different processes on a single chip to form a system for sample pretreatment, separation and detection. This system allows for improved efficiency, making automation possible and reduction in manufacturing cost.

Electroosmotic flow provides a pumping method that is convenient for small capillaries. Electrophoretic separation is shown to be useful. On the left hand side of Fig. 5, glass is bonded on glass after capillaries,  $10\text{ }\mu\text{m} \times 30\text{ }\mu\text{m} \times 1\text{ to }10\text{ cm}$  long, have been etched. Separation of amino acids with up to 75,000 plates/15 sec. has been achieved. Plastic pipette tips inserted in holes in the cover plate acted as reservoirs in which buffer and Pt electrodes were placed. The right hand side of Fig. 1 shows  $\gamma$ -fluorescein isothiocyanate was used as label.

**Harrison et al (1993): MICROMACHINING A MINIATURIZED CAPILLARY  
ELECTROPHORESIS-BASED CHEMICAL ANALYSIS  
SYSTEM ON A CHIP**



**FIG. 5**

### **High Precision. Six Degree-of-Freedom. Non-Contact Optical Sensor**

Mancevski, Qian, Wang, Narayanan, Busch-Vishniac and Buckman (1993) describe the first of a multi-part report on the subject matter. The first part deals with the out-of-plane measurement section of the sensing system, see Fig. 6.

The left hand side of Fig. 6 shows a duolateral effect position sensitive photodiode. The right hand side of Fig. 6 shows the total system; what is needed for this first report, is the out of plane section of the system.

The impetus for this work is the development of cost effective multi-axis, precision position sensing ( $\sim 1\text{-}100\text{ }\mu\text{m}$ ), and the system is to be noncontact, light weight, and capable of simultaneous multi-coordinate sensing. Moreover, the system must be capable of dealing with real time continuous displacement information.

The right hand side of Fig. 6 shows, for out-of-plane sensing, position sensitive devices (PSD). Since each PSD produces four signals which are combined to yield two normalized signals, there is adequate information to determine the out-of-plane distance, among other quantities. Of course, the laser diode triggers the activation of the PSD's.

Mancevski et al (1993):

HIGH PRECISION, SIX DEGREE-OF-FREEDOM,  
NONCONTACT, OPTICAL SENSOR

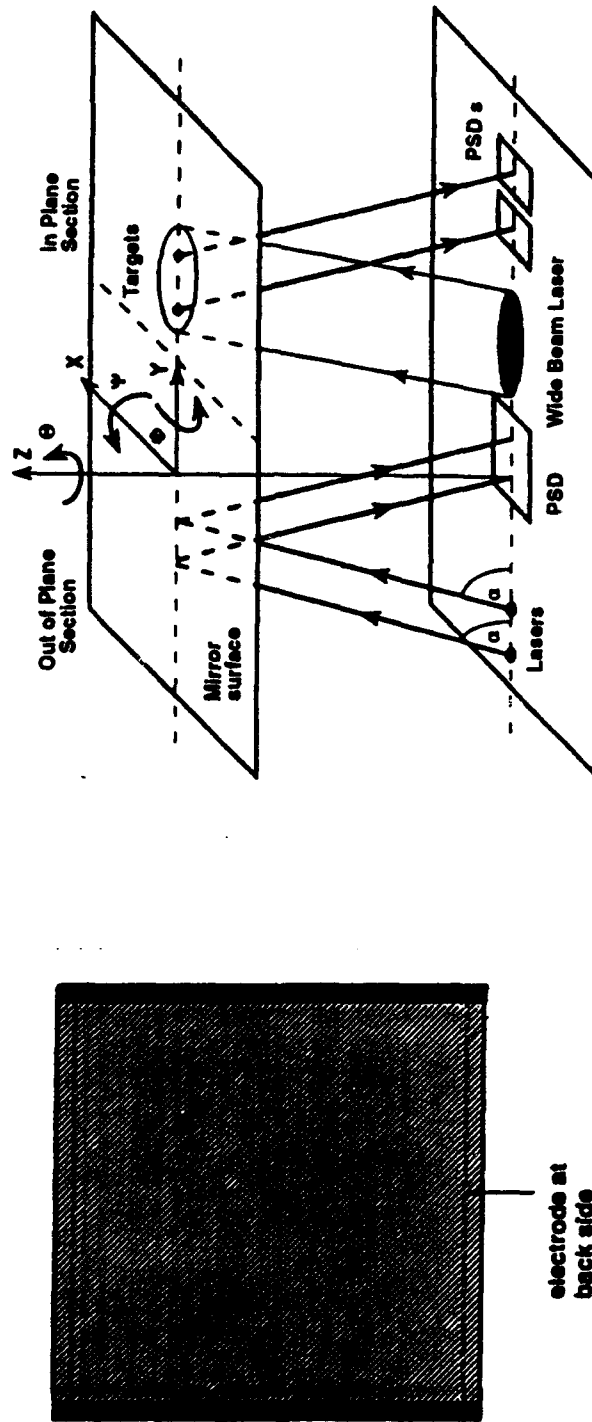


FIG. 6

### **Fluorescent Sensor As An Engine Oil Quality Indicator**

Vinas, Mariciano, Montoro and Iscudero (1992) reported a spectroscopic method to measure the degradation degree of paraffinic mineral oils. The behavior of some molecules in solution versus their surrounding environment (solvent polarity and viscosity) form the basis of the method. Experimental results obtained for Vestan oil confirm the theoretical scheme.

Fig. 7 shows, on top, the interaction, which is of dipole-dipole type, and the shift of the energy level. In it,  $\bar{\mu}_i$  is the dipolar moment of the solute molecule in the  $i$ -th energy level,  $\bar{\mu}_D$  is the dipole moment of solvent molecules in their ground state,  $a$  is the Onsager's cavity radius,  $\alpha$  is the solute polarizability and  $D$  is the static dielectric constant and  $n$  is the refractive index. In addition,

$$f(D,n) = (D-1)/(D+2) - (n^2-1)/(n^2+2); \quad g(n) = (n^2-1)/(n^2+2)$$

The lower part of Fig. 7 shows A, the fluorescence spectra of N-methylindole in Vestan oil at room temperature as fresh oil; B, the worst degradation of the oil.

Vinas et al (1992):

FLUORESCENT SENSOR AS AN ENGINE OIL  
QUALITY INDICATOR

$$\Delta E = -\frac{2}{a^3} f(D, n) \bar{\mu}_i \bullet \bar{\mu}_j - \frac{1}{a^3} g(n) \bar{\mu}_i \bullet \bar{\mu}_j - \frac{4\pi\rho\alpha}{3a^3} \bar{\mu}_D \bullet \bar{\mu}_D + D$$

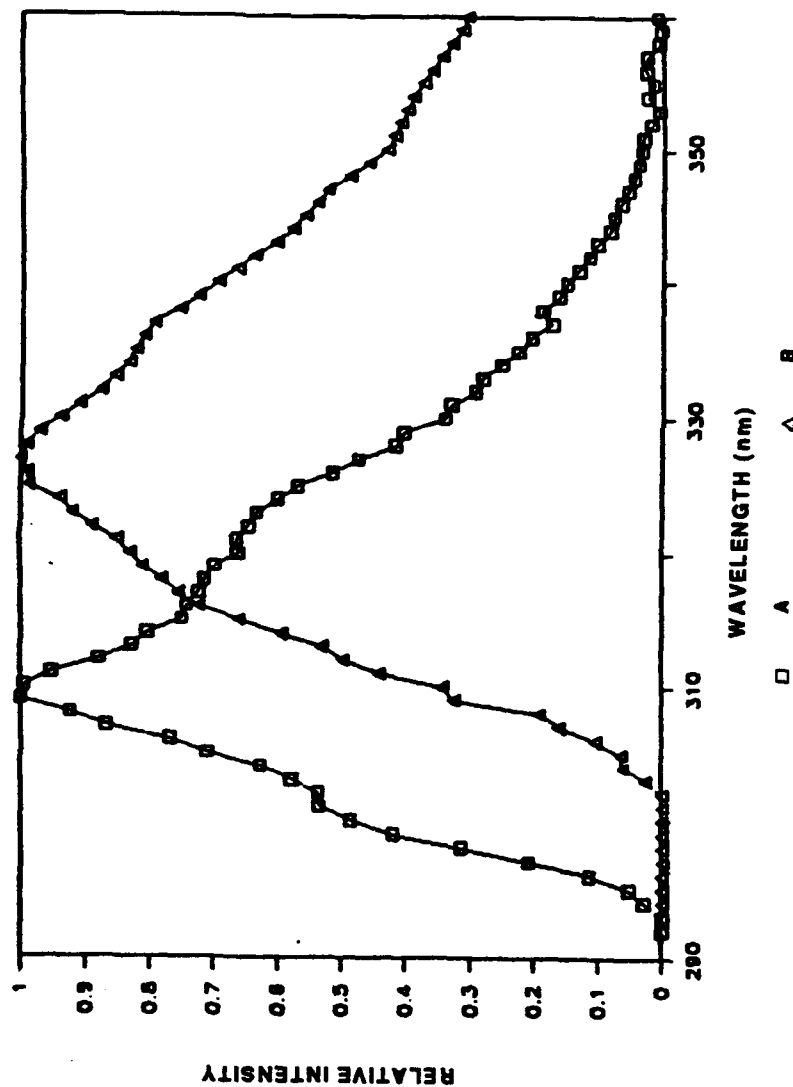


FIG. 7

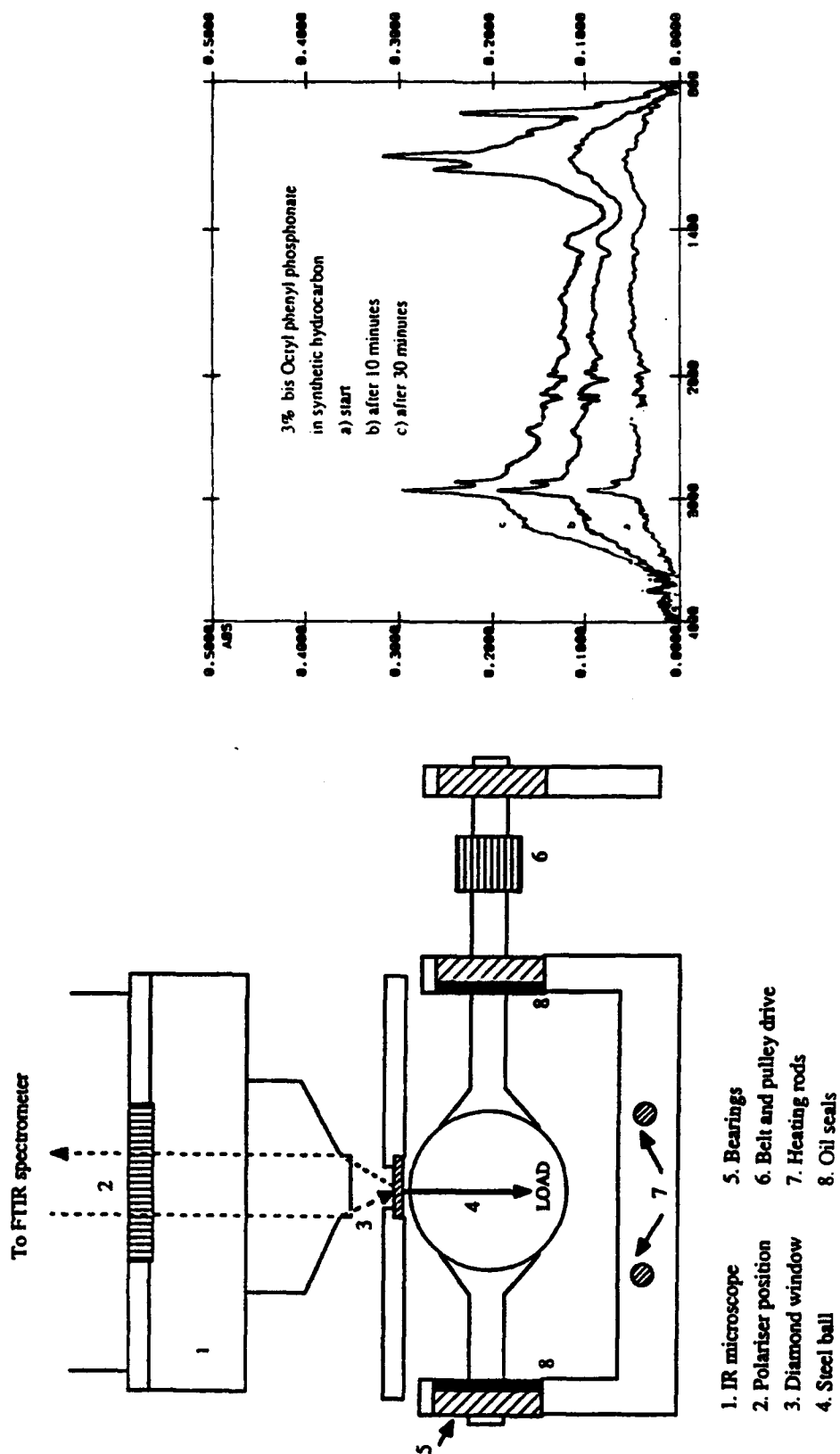
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### **In Lubro Studies of Lubricants in EHD Contacts Using FTIR Absorption Spectroscopy**

Cann and Spikes (1991) reported their research into the physical and chemical processes occurring within lubricated, concentrated contacts by infrared microreflection absorption spectroscopy. The method is applied to the direct determination of the conditions of pressure by experienced by lubricants in contacts, to the formation of antiwear films by phosphorous additives and the study of the alignment of molecules, including viscosity index improvers in contacts.

Fig. 8, on the left hand, shows schematically, the experimental set-up in which a diamond window (3 in the figure) is in contact with a rotating steel ball (4 in the figure). A IR microscope (1 in the figure) and the FTIR spectrometer (2 in the figure) are shown relative to the lubricated contact. The data on the right hand side shows the gradual wear as a function of spatial distance across the half-width of the contact.

# **Cann and Spikes (1991): IN LUBRO STUDIES OF LUBRICANTS IN EHD CONTACTS USING FTIR ABSORPTION SPECTROSCOPY**



**FIG. 8**



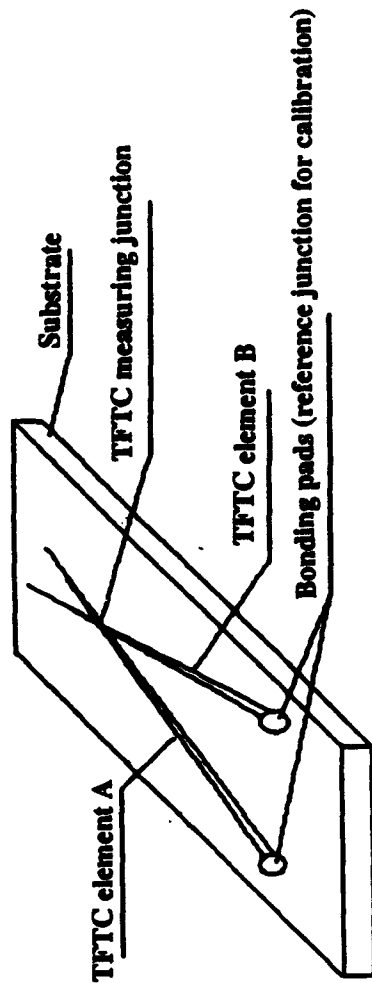
### **Thin Film Thermocouples for Contact Temperature Measurement**

Tian, Kennedy, Deacutis and Henning (1992) reported a procedure for producing thin film thermocouples (TFTC) on the contact surface of sliding mechanical components. The thermocouple devices were made from thin films of vapor deposited copper and nickel. The measuring junctions of the thermocouples were approximately 2  $\mu\text{m}$  thick and between 80  $\mu\text{m}$  and 300  $\mu\text{m}$  across. The response time is less than 1  $\mu\text{s}$ . It was necessary to sandwich the TFTC between a thin film of a hard, non-conducting ceramic ( $\text{Al}_2\text{O}_3$  in this report) for insulating the thermocouple electrically from the substrate and for protecting it during sliding.

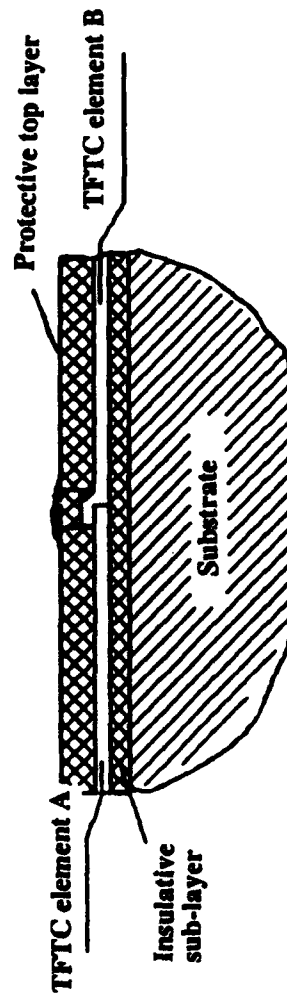
Fig. 9 (a) shows a schematic diagram of the thin film thermocouple and Fig. 9 (b) shows schematically cross-section of the thin film thermocouple.

Tian et al (1993):

# THIN FILM THERMOCOUPLES FOR CONTACT TEMPERATURE MEASUREMENT



(a)—Schematic diagram of thin film thermocouple.



(b)—Schematic cross-section of thin film thermocouple.

FIG. 9

### **On-Line Tribology Measurements on Lubricated Rigid Disks**

Nunnelley and Burleson (1990) reported the use of a high speed ellipsometer for on-line wear measurements of recording media. The instrument makes high speed measurements, at rates of 300 Hz, of the angular dependence of wear damage as the test specimen rotates or determines spatially resolved film thickness profiles across a wear track.

Fig. 10 shows schematically elements of the ellipsometer. A dual phase lock-in amplifier is used to measure the coefficients multiplying the cosine and sine terms oscillating at the frequency  $4\omega$ . These are referred to as the out-of-phase and in-phase signals, respectively. The left hand side of Fig. 10 shows circumferentially averaged wear of thin-metallic-film disk with 30-40 nm carbon overcoat and 3 to 5 nm lubricant. A ceramic slider was used. The slider-disk speed was 100 cm/s with 12 grams slider load.

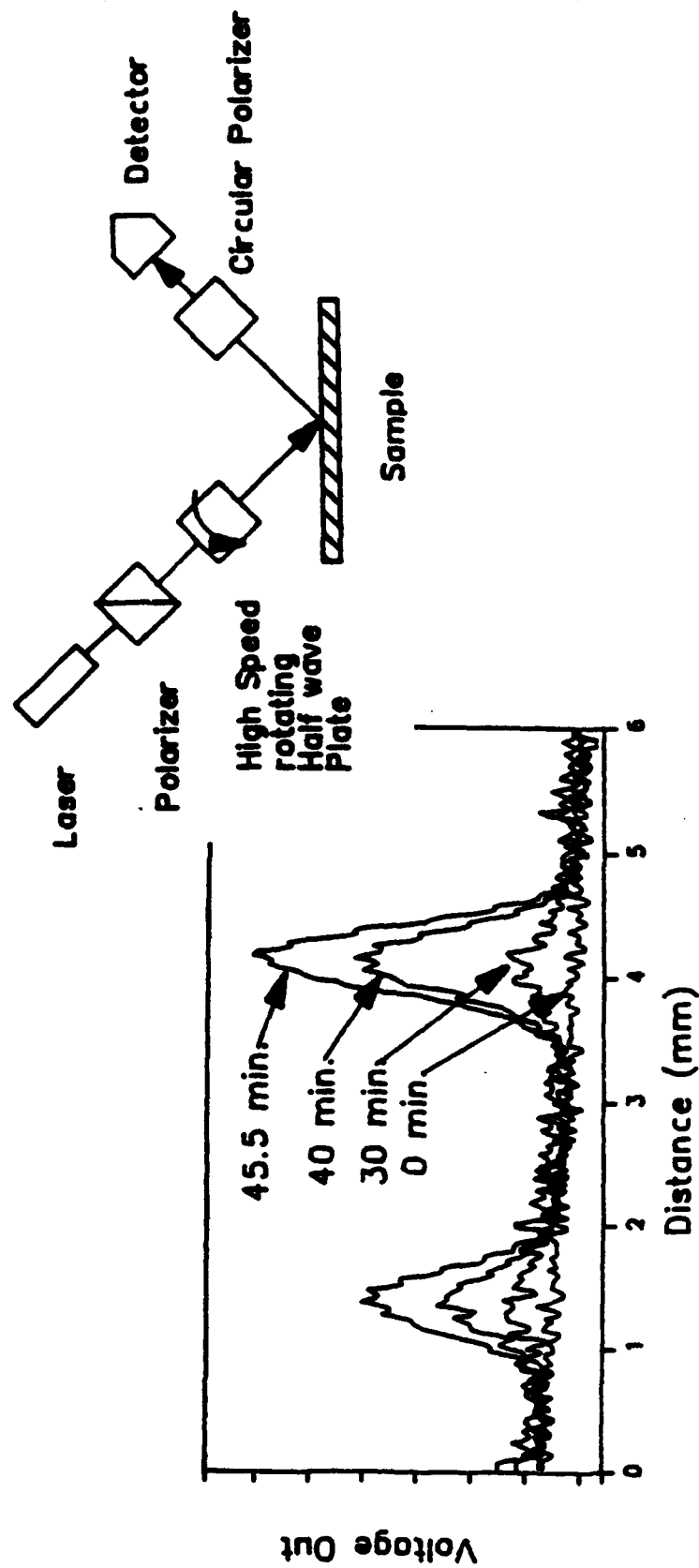


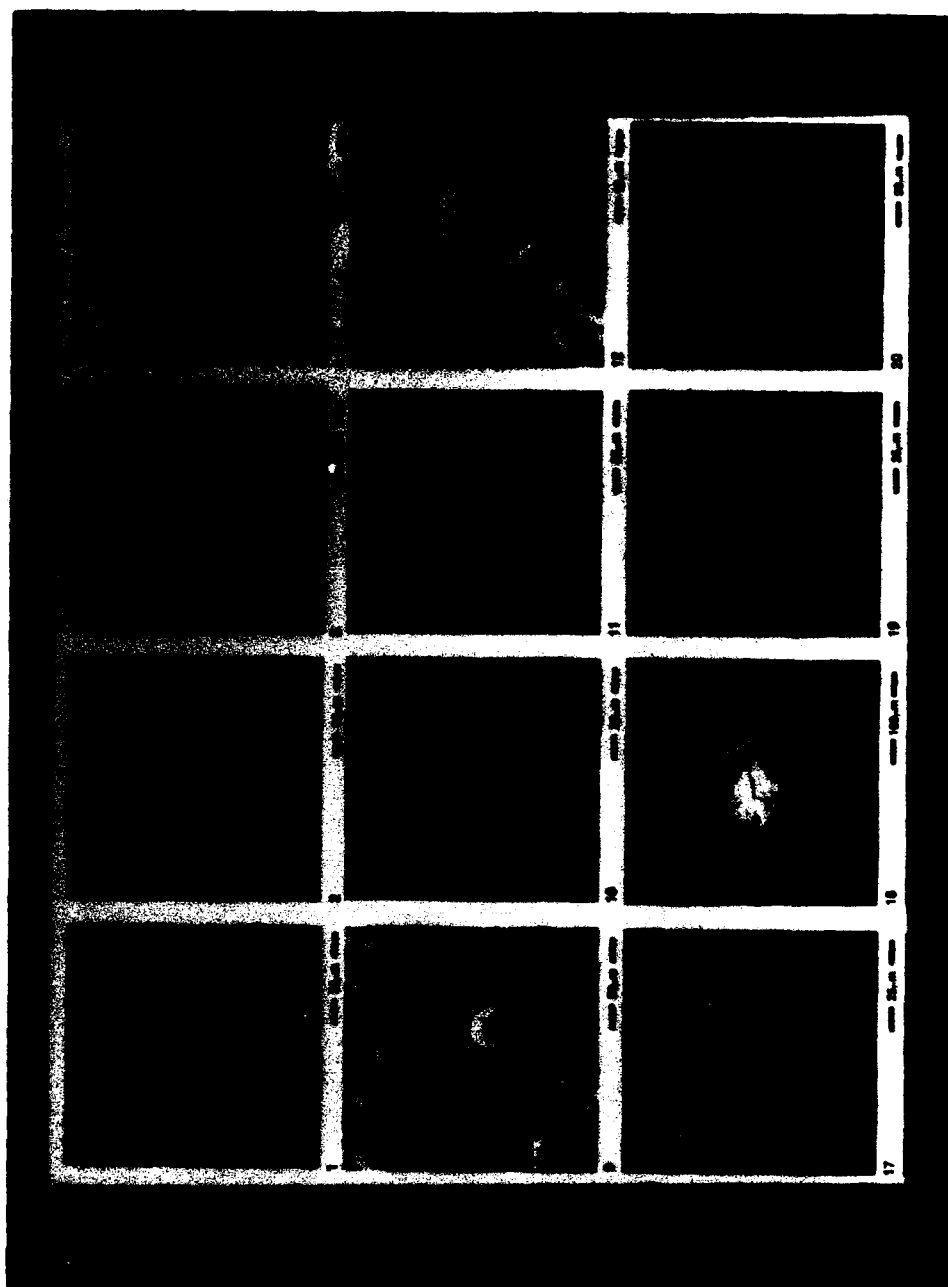
FIG. 10

## **Wear Particles in Lubricating Oils**

Seifert and Westcott (1972), under an Office of Naval Research contract, reported the patented ferrography systems of collecting and precipitating wear particles for detailed examination. The reason for resurrecting this landmark paper is that in the literature searches there are several papers in the 1990 time frame which adopt the idea of ferrography for in-line systems.

To illustrate the diversity of events which may be found in oil samples, consider the following which are shown in Fig. 11: Spherical particles in a bichromatic-high numerical aperture microscope are easily identified because they reflect the image of a pencil placed in the light path (see frame 10 in the figure). Fatigue wear creates particles of distinguishable shape. Fatigue of thorough-hardened 52100 steel creates micron sized spherical particles shown here in a scanning electron microscope (see frame 12 in the figure). Fatigue of case hardened gears creates chunky particles (see frames 17 and 18 in the figure).

**Seifert and Westcott (1972): WEAR PARTICLES IN LUBRICATING OILS**



**FIG. 11**

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## SOME CONCLUDING REMARKS

The literature on sensors has been on a high growth curve. It may be of interest to note that this growth is relatable to one estimate of the world market of fiber optic sensor systems. With the 1990 base figure of \$268 million, the expected level by the year 2000 is \$4.88 billion.\* Approximately half of the use is military; as such, with the decrease in Defense spending the \$4.88 billion may be viewed as an upper bound. The growth rate, of somewhat curtailed, is still impressive indeed.

This project effort has emphasized new ideas which, through additional research, would most likely lead to sensor technologies pertaining to machinery condition in the the next century. Although the reviewing of complementary works on information processing and software engineering, which includes all modelling efforts were not carried out, advances therein have been taken onto consideration in this study.

Taking an observation from across the Atlantic, based in Siemens AG,\*\* it can be paraphrased that the next generation of powerful sensors will be built on the two-prong foundation of: (1) materials re surface and micro-analysis methods, (2) softwares re knowledge-based information conditioning and processing. Note, again, softwares here includes mathematical modelling of measurand functionals.

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\* Montgomery, J.D. and Glasco, J., "Fiber Optic Sensors Long-Range Market Forecast." Proceedings on Fiber Optic Sensors, Arditty, H.J. and Jeunhomme, L.B., eds., SPIE, 586, 2-13 (1985).

\*\* Keinschmidt, P. and Hanrieder, W., "The Future of Sensors, Materials Science or Software Engineering," Sensors and Actuators, A, 33, 5-17 (1992).

## **PROMISING APPROACHES/IDEAS**

**Limiting this discussion to potential research arenas, we see:**

- **Great opportunities to sense, or otherwise detect, symptoms of impending failure modes of machinery through chemical considerations in addition to physical ones which are most often used today.**
- **Indeed, these opportunities are projected in the in-situ and micro-miniature realm.**
- **Advanced modeling of processes leading up to failures will greatly enhance the capabilities of the aforementioned potential for sensing devices.**



## **LITERATURE ON SENSORS**

**Selected records, with abstracts, are shown in anti-chronological order.**

**1993 Title:** QUARTZ CRYSTAL OSCILLATOR USED AS TEMPERATURE SENSOR.

**Author:** Azcondo, F.J.; Peire, J.

**Source:** IECON Proceedings (Industrial Electronics Conference) v 3. Publ by IEEE, Computer Society, Los Alamitos, CA, USA (IEEE cat n 91CH2976-9) p 2580-2585

**Abstract:** A method for obtaining temperature data from a quartz crystal is described. To implement it, the first and third overtones of AT- and SC-cut crystal behavior with temperature have been studied. The AT-cut crystal shows instabilities at unpredictable temperature point while the SC-cut crystal has no activity dips in its c mode of vibration. A circuit to obtain a frequency very sensitive to and linear with temperature changes from the crystal fundamental and third overtone has been developed. Crystal design ideas obtaining the optimum frequency vs. temperature compensation are also explained. The goal of this technique is to compensate frequency vs. temperature variations of a quartz crystal oscillator, obtaining a factor-of-ten improvement over others that use thermistors as temperature sensors. 13 Refs.

**1993 Title:** TRIBOPOLYMERIZATION AND THE BEHAVIOR OF OXYGEN-CONTAINING MONOMERS IN REDUCING CERAMIC WEAR.

**Author:** Furey, M.J.; Kajdas, C.; Kempinski, R; Tripathy, B.S.

**Source:** Proceedings of the 6th International Congress on Tribology 2 p 477-484.

**Abstract:** The lubrication of ceramic materials is a difficult problem; conventional lubrication techniques are limited or often ineffective. Therefore, we have recently developed a new approach to ceramic lubrication. We have demonstrated that the principle of tribopolymerization developed by Furey and Kajdas can be used as a novel and effective approach to designing specific molecular structures for the lubrication of ceramic materials.

This paper outlines our overall research plan to study tribopolymerization as a mechanism of ceramic lubrication. Results of the effects of five oxygen-containing monomers - one condensation type and five addition type - on wear of alumina are also summarized. High contact stress pin-on-disk tests clearly showed that four of these monomers, when added to hexadecane in 1% concentration, reduced alumina ball wear by up to 80%.

Detailed surface analytical studies of one of the additives (C<sub>36</sub> dimer acid/ethylene glycol monoester) using FTIRM, XPS and MS indicate that the mechanism of anti-wear action of this compound on alumina consists of an initial chemical reaction of the monoester with the alumina substrate followed by the formation of oligomer/polymer chains growing outward from the surface.

**1993 Title:** MICROMACHING A MINIATURIZED CAPILLARY ELECTROPHORESIS-BASED CHEMICAL ANALYSIS SYSTEM ON A CHIP.

**Author:** Harrison, D.J; Fluri, K.; Seiler, K.; Fan, Z.; Effenhauser, C.S.; Manz, A.

**Source:** Science v 21 p 895.

**Abstract:** Micromachining technology was used to prepare chemical analysis systems on glass chips (1 centimeter by 2 centimeters or larger) that utilize electroosmotic pumping to drive fluid flow and electrophoretic separation to distinguish sample components. Capillaries 10 to 10 centimeters long etched in the glass (cross section, 20 micrometers by 30 micrometers) allow for capillary electrophoresis based-separations of amino acids with up to 75,000 theoretical plates in about 15 seconds, and separations of about 600 plates can be effected within 4 seconds. Sample treatment steps within a manifold of intersecting capillaries were demonstrated for a simple sample dilution process. Manipulation of the applied voltages controlled the directions of fluid flow within the manifold. The principles demonstrated in this study can be used to develop a miniaturized system for sample handling and separation with no moving parts.

**1993 Title: BRAGG GRATING-TUNED FIBER LASER STRAIN SENSOR SYSTEM.**

**Author:** Melle, Serge M.; Alavie, Tino; Karr, Shawn; Coroy, Trent; Liu, Kexing; Measures, Raymond M.

**Source:** IEEE Photonics Technology Letters v 5 n 2 Feb p 263-266

**Abstract:** The development of a fiber laser sensor system which permits efficient interrogation of Bragg grating sensors is reported. A tunable erbium fiber laser which utilizes a broad-band mirror and an intracore Bragg grating reflector in a side-pump configuration is described. The wavelength of the laser oscillation is determined by the Bragg grating, which is remotely located and used as a strain sensor. This arrangement is employed in conjunction with a passive wavelength demodulation system (WDS) to form a self-contained fiber laser strain sensor system, allowing efficient interrogation of the Bragg sensor. The device provides interrupt immune sensing of static and dynamic strains with a resolution of 5.4  $\mu\epsilon$  and a bandwidth of 13.0 kHz. (Author abstract) 9 Refs.

**1993 Title: A PHOTOMICRODYNAMIC SYSTEM WITH A MECHANICAL RESONATOR MONOLITHICALLY INTEGRATED WITH LASER DIODES ON GALLIUM ARSENIDE.**

**Author:** Ukita, H.; Uenishi, Y.; Tanaka, H.

**Source:** Science v 260 p 786.

**Abstract:** A cantilever resonant microbeam, laser diodes, and a photodiode have been fabricated on the surface of a gallium arsenide substrate. The microbeam is excited photothermally by output caused by the difference in optical length between the microbeam and another laser diode. A high carrier-to-noise ratio (45 decibels) is achieved with a short (3 micrometers) external cavity length. Such a small distance allows a lensless system, which increases the ease of fabrication. This work could lead to applications in

which photomicrodynamic systems are monolithically integrated on a gallium arsenide substrate with surface micromachining technology.

**1992 Title:** FERROGRAPHIC ANALYSIS OF FAILURE PROCESS IN A FULL-SCALE JOURNAL BEARING.

**Author:** Akagaki, T.; Kato, K.

**Source:** Wear v 152 n 2 Jan 31 p 241-252

**Abstract:** The failure process of a full-scale journal bearing, caused by insufficient oil supply to the interface, was monitored and analyzed with ferrography and the spectrometric oil analysis procedure (SOAP). The temperature of the bearing metal and the journal deviation were also measured to monitor the behavior of the bearing. Wear debris was observed and analyzed in detail with a scanning electron microscope and a wavelength-dispersive X-ray analysis facility. It was found that ferrography and SOAP could promptly detect the failure symptoms. Ferrography could also detect the progressive failure, that is the progress of damage. With the progress of failure, the types, sizes and composition of wear debris changed significantly; a small amount of rubbing debris was generated from the journal at the normal state, much cutting and plate-like debris from the journal, some plate-like debris from the bearing at the early stage of failure, much polymer-like debris containing both the journal and bearing materials at the middle stage and much cutting, plate-like and oxide-like debris from both the journal and lining metal (steel) at the catastrophic stage. The wear mechanisms are discussed. (Author abstract) 18 Refs.

**1992 Title:** WAVELENGTH-DEMULPLEXED FIBER-OPTIC TEMPERATURE- MEASUREMENT INSTRUMENT.

**Author:** Andreev, A.; Diankov, G.; Zafirova, B.; Kebedjiev, A.

**Source:** Sensors and Actuators, A: Physical v 30 n 3 Feb p 215-218

**Abstract:** We report a transmission fiber-optic temperature sensor consisting of a semiconductor chip coupled between two parallel fiber ends. Wavelength demultiplexing of the signal and reference arms improves the overall instruments performance: dynamic range, insertion loss and linearity. Practical requirements for the associated electronic blocks are also discussed. (Author abstract) 3 Refs.

**1992 Title:** LARGE-BANDWIDTH REFLECTION FIBER-OPTIC SENSORS FOR TURBOMACHINERY ROTOR BLADE DIAGNOSTICS.

**Author:** Andrenelli, L.; Paone, N.; Rossi, G. L.

**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 539-542

**Abstract:** It is possible to measure rotating blade vibrations in a turbomachine by stationary sensors mounted on the casing. Optical sensors appear best suited for these measurements. A prototype fiber-optic sensor is proposed, its scheme is described and its performance presented. The design choices are discussed with respect to the desired performance; general

conclusions about the use of optical sensors for such measurements are drawn

**1992 Title:** FIBER-OPTIC PHOTOTHERMAL INTERFEROMETRIC SENSOR (FOPIS): A NOVEL TECHNIQUE FOR CHEMICAL MEASUREMENTS.

**Author:** Balconi, Luisa; Martinelli, Mario; Sigon, Fabio; Vegetti, Giorgio

**Source:** Process Control and Quality v 3 n 1-4 Dec p 107-114

**Abstract:** Corrosion, scaling and deposition effects in the water-steam side represent a cause of unavailability in electric power plants. Cycle chemistry control is essential in order to prevent or eliminate them. The aim of this communication is to present an original fiber-optic sensor approach to the detection of chemical species in aqueous solution, for process fluid monitoring. The working principle of the sensor relies on Interferometric Photothermal Spectroscopy. Presence of an analyte in the process fluid causes absorption of light of a specific wavelength, transmitted by an appropriate fiber-optic cable. The subsequent thermal decay induces an optical path change in the fluid, which is detected by an advanced fiber-optic interferometric probe. Therefore, the chemical sensor head is completely fiber-optics based, and can be differently configured to the specific monitoring needs (analyte, concentration range, chemical-physical parameters) while maintaining its characteristics of low-invasivity, chemical inertness and e.m. safety. An example of laboratory detection of Fe ions in typical process fluid concentrations is given. The sensor may constitute the basis for the development of a photonic chemical sensing network. (Author abstract) 8 Refs.

**1992 Title:** THE DESIGN OF A MONOLITHIC, SIGNAL CONDITIONED PRESSURE SENSOR.

**Author:** Baskett, Ira; Frank, Randy; Ramsland, Eric

**Source:** Proceedings of the Custom Integrated Circuits Conference. Publ by IEEE, IEEE Service Center, Piscataway, NJ, USA (IEEE cat n 91CH2994-2) p 4p

**Abstract:** A bipolar IC process has been used to design and manufacture a pressure sensor that includes temperature compensation and amplification in a monolithic silicon structure. Specifically, a bipolar IC process has been combined with a micromachined silicon diaphragm and piezoresistive sensing element to produce a fully integrated pressure sensor. The result of this effort is a sensor that is easy to manufacture and can be directly interfaced to a microprocessor with an integral analog-to-digital converter. This allows a considerable reduction in space and the simplification of external circuitry for systems that require a pressure input. The design of the single element sensor, circuitry, and key processing aspects are discussed. 2 Refs.

**1992 Title:** NAVAL FIBER OPTIC SYSTEM DEVELOPMENT PROGRAM.

**Author:** Blackwell, Luther

**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 1589. Publ by Int Soc for Optical Engineering, Bellingham, WA, USA p 69-82

**Abstract:** This paper provides an overview of the major fiber optic developments within the Department of the Navy, concentrating on developments within the Naval Sea Systems Command (NAVSEA). Most of the fiber optic programs discussed were approved at the Chief Of Naval Operations (CNO) executive board (CEB) meeting September 1990, and they include programs to develop standard fiber optic components and networks. These efforts are intended to capitalize on commercial industry products that use industry standards and open system architecture approaches such as FDDI, BISDN, and FUTUREBUS plus . Full military specifications will be imposed only when required, since both commercial and ruggedized equipments also will be installed on ships. 11 refs.

**1992 Title:** MECHANICAL RESONANCE GAS SENSORS WITH PIEZOELECTRIC EXCITATION AND DETECTION USING PVDF POLYMER FOILS.

**Author:** Block, R.; Fickler, G.; Lindner, G.; Mueller, H.; Wohnhas, M.

**Source:** Sensors and Actuators, B: Chemical v B7 n 1-3 Mar p 596-601

**Abstract:** A simple mechanical resonator sensor fabricated out of a glass plate acting as a vibration cantilever beam and interrogated with piezoelectric polyvinylidene fluoride polymer foils glued on both sides of the plate is described and characterized with respect to gas-sensing applications. The sensitivity of this device allows binary gas mixtures to be controlled at an accuracy level of a few percent, which can be enhanced by the mode-coupling effect, i.e., the coupling of flexural and torsional vibrations of neighboring resonance frequency. (Edited author abstract) 10 Refs.

**1992 Title:** OPTICAL AND PIEZOELECTRIC ANALYSIS OF POLYMER FILMS FOR CHEMICAL SENSOR CHARACTERIZATION.

**Author:** Bowman, Elizabeth M.; Burgess, Lloyd W.; Wenzel, Stuart W.; White, Richard M.

**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 1587. Publ by Int Soc for Optical Engineering, Bellingham, WA, USA p 147-157

**Abstract:** The responses of a polymeric optical waveguide sensor and a polymer coated Lamb wave piezoelectric sensor are used to characterize the chemical interaction of an analyte with the polymer layer. Information in the sensor response about polymer swelling, pore filling, mass loading, and changes in viscoelastic properties can be used to elucidate the interaction mechanism. Additionally, using two types of sensors in a mixed array increases selectivity by providing different information about the same sample. The complementary nature of these two sensors and their response mechanisms are explored. 15 refs.

**1992 Title:** LONG-TERM PERFORMANCE OF FIBER OPTIC CABLE PLANT IN NAVY SHIPS.

**Author:** Brown, Gair D.; Ingold, Joseph P.; Paxton, Jack G. Jr.

**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 1589. Publ by Int Soc for Optical Engineering, Bellingham, WA, USA p 58-68

**Abstract:** A fiber-optic cable plant installed on the AEGIS cruiser USS Mobile Bay (CG 53) provides the opportunity to study the long term effects of the shipboard environment on passive fiber optic components. The current study consists of periodic inspections of the cable plant, including visual examination of connectors and OTDR measurements of the fibers. Measurements to date show no significant adverse impact to the performance characteristics of the fiber optic components from the shipboard environment. 2 refs.

**1992 Title:** DYNAMIC WEAR TESTS IN THE SEM.

**Author:** Calabrese, S.J.; Ling, F.F.; Murray, S. F.

**Source:** ASLE Transactions v 26 4 p 455-465.

**Abstract:** Wear studies were conducted in the chamber of a scanning electron microscope (SEM) to permit direct observations of the wear processes. The sliding specimens had been metallographically polished and etched prior to test so that the effect of the alloy microstructures could be observed. Test alloys included: low and high carbon steels, stainless steels, and bronze. As wear particles were generated, and became trapped in the interface, they produced surface damage which was in the form of material removed, or metal transfer to one of the sliding members. Video tape records were made at magnification up to 8000X and photomicrographs were taken at high magnification to show the geometry of the wear particles.

**1992 Title:** SILICON PRESSURE SENSOR WITH INTEGRATED BIAS STABILIZATION AND TEMPERATURE COMPENSATION.

**Author:** Crazzolara, H.; von Munch, W.; Nagele, M.

**Source:** Sensors and Actuators, A: Physical v 30 n 3 Feb p 241-247

**Abstract:** A piezoresistive pressure sensor for relative or differential pressure applications has been developed. The use of a 10  $\mu$ m thick bossed membrane provides high sensitivity (typically 3.3  $\mu$ V/V Pa) in the low-pressure range (0-60 hPa). Adaptation of sensor fabrication to a triple-diffusion bipolar process by application of an electrochemical etch-stop at a diffused n-type layer on a p-substrate allows monolithic integration of two different conditioning circuits operating with battery voltages of 12 to 20 V. Both circuits provide bias stabilization and temperature compensation for temperatures between minus 30 and plus 90 degree C. Thus the possibility of sensor fabrication by using standard IC technologies is demonstrated. (Author abstract) 9 Refs.

**1992 Title:** PROCEEDINGS OF EUROSensors V.

**Author:** D'Amico, A. (Ed. )

**Source:** Sensors and Actuators, B: Chemical v B6 n 1-3 Jan.

**Abstract:** This issue of the journal contains Part I of the conference proceedings, with 56 papers, grouped under the following topics: plenary lectures; chemical sensors; biosensors I; gas sensors I; biosensors II; applications; physical sensors; gas sensors II; ion sensors; and technology. Some of the subjects discussed by the papers are here cited as examples: neuronal networks for biochemical sensing; application-specific design of a piezoelectric chemosensor array; application of an electronic nose to the discrimination of coffees; biosensors for medical applications; direct monitoring of antigen-antibody interactions by spectral interferometry; a love plate biosensor utilizing a polymer layer; performance of hydrogen-sensitive MOS capacitances with integrated on-chip signal conditioning; evaluation of conducting LB films based on ethylenedithiotetrathiafulvalene (EDT-TTF) derivatives for phosphine sensing; air pollution monitoring with a semiconductor gas sensor array system; detection of methane/butane mixtures in air by a set of two microcalorimetric sensors; dip-coating process for preparation of ion-sensitive NASICON thin films; and simulation of ISFET operation based on the site-binding model. All papers are abstracted separately.

**1992 Title:** PROCEEDINGS OF EUROSensors V.

**Author:** D'Amico, A. (Ed. )

**Source:** Sensors and Actuators, B: Chemical v B7 n 1-3 Mar.

**Abstract:** This issue of the journal contains 89 papers from a European conference on the fabrication and applications of a great variety of chemical and electrochemical sensors. Topics discussed include biomedical sensors, the technology of biosensors, enzyme sensors, Langmuir-Blodgett sensors, plant-based sensors, humidity sensors, optical chemical sensors, the technology of chemical sensors, solid-state chemical sensors, sensors for environmental applications, fluorescent-decay temperature sensors, sensors for determining metal ions, ion-selective field effect transistor (ISFET) sensors, acoustic and ultrasonic sensors, solid-state gas sensors, chlorine sensors, the technology of gas sensors, hydrogen sensors, tin dioxide based sensors, oxygen sensors, optical fiber chemical sensors, and automotive exhaust gas sensors. All papers are indexed and abstracted separately.

**1992 Title:** PROCEEDINGS OF EUROSensors V.

**Author:** D'Amico, A. (Ed. )

**Source:** Sensors and Actuators, A: Physical v 31 n 1-3 pt 3 Mar.

**Abstract:** This conference proceedings contain 45 papers. Topics covered include: Applications of sensors for flow, eddy current, and position sensing, automobile sensors, and surface topography sensing; Physical sensors for tactile imaging, force measurement, acoustic emission monitoring, accelerometers, fabrication and design processes, strain gages, thick-film multisensors, condensor microphones, pressure and temperature sensors,



torque measurement, object recognition, magnetotransistors, and magnetic field sensors; Optics and Radiation sensors including pyroelectric sensor arrays, optocouplers, smart sensors, drift detectors, nuclear radiation detectors; and Technology issues like micromachining, etching and instability in sensors.

**1992 Title:** PROCEEDINGS OF EUROSENSORS V.

**Author:** D'Amico, A. (Ed. )

**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr. Publ by Elsevier Sequoia SA, Subscription Department, Lausanne 1, Switz p 291-720

**Abstract:** The Proceedings materials contain 69 papers. The topics covered include biomedical sensors, sensor fabrication, capacitance-based sensors, chemical sensors, silicon sensor fabrication, acceleration sensors, infrared sensors, thermal sensors, optical sensors and imaging, high-energy radiation sensors, data processing, mechanical sensors, acoustic and ultrasonicsensors, resonant and displacement sensors, pressure, magnetic and optical fiber sensors. All papers are abstracted and indexed separately.

**1992 Title:** PURE AND CALCIUM-MODIFIED LEAD TITANATE CERAMICS FOR PYROELECTRIC SENSORS.

**Author:** de Frutos, J.; Jimenez, B.

**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 393-395

**Abstract:** In this work, experimental data on the evolution of pyroelectric and non-pyroelectric currents in pure lead titanate ceramic materials and their modifications with calcium are presented. These data have been obtained for different Ca contents, for several poling fields and at different temperatures, as a function of the frequency. Because of the lack of a uniform distribution of the polarization inside the materials, the response to thermal stimulus depends on which surface is irradiated by the infrared (IR) radiation. This is the reason why the data are presented indicating the face exposed to the radiation. The data are complemented with P-T diagrams and remanent  $d//3//3$  studies. Based on the data obtained, the use of the optimal lead titanate ceramic composition for the sensor is proposed.

**1992 Title:** COMPACT OPTICAL CHEMICAL SENSOR BASED ON SURFACE PLASMON INTERROGATION.

**Author:** De Maria, L.; Martinelli, M.

**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 710-712

**Abstract:** An optical sensor based on surface plasmon waves (SPW) interrogation for chemical sensing has been developed. The optical set-up is fabricated in a compact way by means of a resonant scanner which provides an angularly spread beam incident to the sensing element. The angular position of the excited surface plasmon depends on the chemical species at the surface. The instrument has been tested to detect small variation of refractive index of aliquid mixture in contact with the film.

- 1992 Title:** COMPARISON BETWEEN MICROMACHINED PRESSURE SENSORS USING QUARTZ OR SILICON VIBRATING BEAMS.  
**Author:** Dufour, M.; Delaye, M. T.; Michel, F.; Danel, J. S.; Diem, B.; Delapierre, G.  
**Source:** Sensors and Actuators, A: Physical v 34 n 3 Sep p 201-209  
**Abstract:** In this comparison between quartz and silicon as convenient materials for micromachined pressure sensors, we first examine the mechanical properties of the materials, then the technical and technological problems connected with the design of the resonator itself. Next, attention is paid to the mechanical chain by means of which the external pressure is converted into stress applied to the resonator. Finally, questions related to the whole device (packaging, interconnecting) are discussed. (Author abstract) 11 Refs.
- 1992 Title:** NON-CONTACT ABSOLUTE POSITION MEASUREMENT USING A COMPACT DISC PLAYER OPTICAL PICK-UP.  
**Author:** During, C.; Andersson, S.; Wilkander, J.  
**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 575-581  
**Abstract:** An optical pick-up from a compact disc player is used as an absolute position sensor. The output from the pick-up gives the optical reflectivity profile from an object on which the measurement is to be taken. The object's position is given from the correlation between a pre-sampled reference of the reflectivity profile and actual samples of the same profile. The method is demonstrated for position/angle measurement of a smooth handpolished rotating aluminum disc.
- 1992 Title:** SILICON OPTICAL PRESSURE SENSOR.  
**Author:** Dziuban, J. A.; Gorecka-Drzazga, A.; Lipowicz, U.  
**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 628-631  
**Abstract:** A novel optical-fiber silicon pressure sensor with a bossed membrane has been fabricated. The pressure deflects the micromachined thin membrane and moves the end of a fiber illuminating the p-n junction fabricated near the edge of the membrane in a standard IC process. A photovoltage proportional to the degree of deflection of the membrane is generated in the junction. A nontypical output voltage versus inlet pressure characteristic has been obtained.
- 1992 Title:** GAS SENSOR SYSTEM WITH DIELECTRIC AND MASS SENSORS.  
**Author:** Endres, H. -E.; Mickle, L. D.; Koesslinger, C.; Drost, S.; Hutter, F.  
**Source:** Sensors and Actuators, B: Chemical v B6 n 1-3 Jan p 285-288  
**Abstract:** A basic principle of gas sensors is that under the influence of gases a sensitive layer changes its properties, which are measured by a transducer. Normally, a sensor operates only with one specific property of the sensitive material, e.g., the permittivity. This paper proposes a sensor system that uses the measurement of different physical properties (permittivity, mass,

refractivity, etc.) of one sensitive material by various transducers to improve the characteristics (e.g., selectivity, stability) of the whole system. The design concept of such a sensor system is given in the first Section. In this paper the SO<sub>2</sub> adsorption of a particular sensitive material is measured with a dielectric sensor (interdigital capacitor, IDC) and a mass sensor (10 MHz bulk wave oscillator, BAW). The two adsorption isotherms show significant differences. The dielectric-adsorption isotherm reaches its saturation point at a lower SO<sub>2</sub> concentration than the mass-adsorption isotherm. This effect can be used to determine the saturation point exactly and to avoid the ambiguity of a single sensor signal in a sensor system. (Author abstract) 9 Refs.

**1992 Title: SOI PRESSURE SENSOR.**

**Author:** French, P. J.; Muro, H.; Shinohara, T.; Nojiri, H.; Kaneko, H.

**Source:** Sensors and Actuators, A: Physical v 35 n 1 Oct p 17-22

**Abstract:** A single-crystal silicon piezoresistor has a high sensitivity to strain but has the problem of leakage at the pn junction at elevated temperatures. This usually limits the applications of these devices to less than approximately equals 150 degree C. This paper presents a technique for fabricating a single-crystal silicon-on-oxide (SOI) pressure sensor for high-temperature applications. The SOI structure is formed from the substrate by a combination of trench etching and anisotropic etching techniques. The desired SOI island is under-etched using an anisotropic etch and then separated from the substrate by an oxidation step. The problems associated with etching convex corners have been avoided by using two trench etchings. The remaining cavities are refilled by polysilicon deposition. By using this technique, a good-quality single crystal can be achieved, without requiring lengthy or expensive processing. (Author abstract) 10 Refs.

**1992 Title: FABRICATION OF MICRODIAPHRAGM PRESSURE SENSOR UTILIZING MICROMACHINING.**

**Author:** Fujii, Tetsuo; Gotoh, Yoshitaka; Kuroyanagi, Susumu

**Source:** Sensors and Actuators, A: Physical v 34 n 3 Sep p 217-224

**Abstract:** A newly structured microdiaphragm and its fabrication process have been developed utilizing micromachining (wafer direct bonding, preferential polishing of polysilicon, laser boring and anisotropic etching). This microdiaphragm has a pressure-inlet port perpendicularly bored from the reverse surface. By adapting this structure to the pressure sensor, different pressure measurements can be performed on a single chip. This microdiaphragm pressure sensor has a diaphragm that is smaller than 100  $\mu$ m in size and allows itself to be installed anywhere on a chip. As an intelligent pressure sensor, it is advantageously integrated with a large-scale integrated circuit. (Author abstract) 10 Refs.

**1992 Title: ELASTIC WAVE SENSORS - QUARTZ TECHNOLOGICAL CHANNEL AND SILICON TECHNOLOGY.**

**Author:** Hauden, D.; Hoummady, M.; Choujaa, A.; Bastien, F.

**Source:** Sensors and Actuators, A: Physical v 33 n 1-2 May p 99-102

**Abstract:** Elastic wave sensors use the vibrating mechanical properties of materials, generally monocrystalline and piezoelectric, such as quartz crystal or lithium niobate. Within such materials, elastic waves are easy to generate and to detect after propagation by means of plate electrodes (bulk waves) or interdigital transducers (IDT) (surface waves or bulk waves). The sensitive signal of such sensors can be measured in terms of intensity (attenuation of the signal) or frequency, with oscillating electronic loop, or in-phase versus an arbitrary or out of phase reference. Among quartz crystal sensors, a particularly interesting new family has been studied: sensors using transverse horizontal waves (TH sensors). In recent years, elastic wave sensors on silicon have been studied. The piezoelectric layer deposited on the silicon substrate must be compatible with the usual silicon process used in microelectronics, and also with the micromachining made generally chemically in 3-D. (Author abstract) 18 Refs.

**1992 Title:** CONTROLLED SELECTIVITY OF POLYSILOXANE COATINGS: THEIR USE IN CAPACITANCE SENSORS.

**Author:** Haug, M.; Schierbaum, K. D.; Endres, H. E.; Drost, S.; Goepel, W.

**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 326-332

**Abstract:** Capacitance sensors were prepared by spin-on coating interdigital thin-film structures with chemically modified polymers. The sensors were characterized electrically by their frequency response behaviour and spectroscopically by Fourier transform infrared spectroscopy (FTIR). The electrical response of the structures was monitored by impedance spectroscopy at different frequencies, temperatures and partial pressures of organic aliphatic and aromatic compounds in air. At an optimum frequency and temperature, the capacitance part in the sensor response was then used for systematic sensor tests. The results are explained by a solution of organic gases in the polymer. Implications are discussed to tailor the polymer coatings for specific selectivities.

**1992 Title:** OPTICAL FIBRE VORTEX SENSOR FOR FLOWRATE MEASUREMENTS.

**Author:** Herzog, J. P.

**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 696-700

**Abstract:** An optical fibre vortex shedding flowmeter is presented, which uses the detected light intensity variations induced by the vortices at the output of a multimode optical fibre in order to determine the vortex shedding frequency. This frequency gives a measure of the flowrate crossing the flowmeter. The device is tested on industrial test rigs in the case of water flow. Applications of such an optical fibre device could be found in industrial processes where the flowrate of explosive media has to be measured or in areas with strong electromagnetic interferences.

**1992 Title:** LIQUID DENSITY SENSING BY USING A PHOTOTHERMAL VIBRATION.

**Author:** Inaba, Seiki; Okuhara, Yoshiki; Hane, Kazuhiro

**Source:** Sensors and Actuators, A: Physical v 33 n 3 Jun p 163-166

**Abstract:** An optical sensing system for measuring liquid density, which uses the resonance frequency shift of a membrane vibrated by the photothermal effect in liquid, is described. On increasing the liquid density from 0.79 to 1.18 g/cm<sup>3</sup>, the resonance frequency for the membrane with a cantilever structure decreased monotonically from 1940 to 1700 Hz by sound radiation from the vibrating membrane. (Author abstract) 14 Refs.

**1992 Title:** FIBER OPTIC PRESSURE SENSOR.

**Author:** Ingold, Joseph P.; Sun, Mei H.; Bigelow, Russell N.

**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 1589. Publ by Int Soc for Optical Engineering, Bellingham, WA, USA p 83-89

**Abstract:** This paper highlights the efforts of the Naval Surface Warfare Center to develop a fiber optic pressure transducer. The initial application for this fiber optic sensor is to monitor the pressure in the sonar dome of a surface ship. This required a 0 - 100 pounds per square inch (gage) sensor. This sensor, developed by Luxtron, Incorporated, under a Small Business Innovative Research contract, utilizes a vibrating quartz crystal as the transduction mechanism. Changes in the resonant frequency of the quartz crystal as a result of force applied to the crystal is monitored using a simple fiber optic link. This paper discusses the principle of operation and design of the sensor, advantages and disadvantages of this type of sensor, development results to date, and future development plans. Portions of this paper have been presented previously in the paper, 'Fiberoptic pressure sensor based on vibrating quartz crystal technology,' presented at the International Congress on Optical Science and Engineering, The Hague, Netherlands, March 1990. 3 refs.

**1992 Title:** FIBER-OPTIC BRAGG-GRATING DIFFERENTIAL-TEMPERATURE SENSOR.

**Author:** Kersey, A. D.; Berkoff, T. A.

**Source:** IEEE Photonics Technology Letters v 4 n 10 Oct p 1183-1185

**Abstract:** A differential temperature sensor based on fiber-optic Bragg-grating elements is described. A high sensitivity to thermally induced Bragg wavelength shifts is obtained using an interferometric detection approach. Results presented show a temperature resolution of less than 0.05 degree C, corresponding to a Bragg wavelength shift resolution of less than 6 multiplied by 10<sup>-4</sup> nm. 5 Refs.

**1992 Title:** MULTIPLEXED PIEZOELECTRIC POLYMER TACTILE SENSOR.

**Author:** Kolesar, Edward S. Jr.; Reston, Rocky R.; Ford, Douglas G.; Fitch, Robert C. Jr.

**Source:** Journal of Robotic Systems v 9 n 1 Feb p 37-63

**Abstract:** An electrically multiplexed robotic tactile sensor has been realized using a monolithic silicon-integrated circuit coupled to a piezoelectric polyvinylidene fluoride (PVDF) film. The integrated circuit incorporates 25 sensor electrodes arranged in a symmetrical 5 multiplied by 5 matrix. Each electrode occupies a 600 multiplied by 600  $\mu\text{m}$  square area, and they are separated from each other by 600  $\mu\text{m}$ . A 25-  $\mu\text{m}$  thick PVDF film was experimentally determined to be compatible with the fabrication process, and also yielded very favorable tactile sensing performance characteristics. The response of the tactile sensor is essentially linear for loads spanning 0.8 to 60 g force (gmf). The response bandwidth is 33 Hz, the hysteresis level is very small, and crosstalk is not a significant problem. A novel precharge bias scheme has been implemented to stabilize the pre- and postload sensor response. A rudimentary tactile object image measurement process was evaluated to recognize the shapes of circular, rectangular, toroidal, and hexagonal loads. (Author abstract) 101 Refs.

**1992 Title:** OPTICALLY EXCITED SILICON SENSOR FOR PERMANENTLY INSTALLED DOWNHOLE PRESSURE MONITORING APPLICATIONS.

**Author:** Kvisteroy, Terje; Gusland, Ole Henrik; Stark, Birger; Nakstad, Hilde; Eriksrud, Morten; Bjornstad, Bjorn

**Source:** Sensors and Actuators, A: Physical v 31 n 1-3 pt 3 Mar p 164-167

**Abstract:** The paper presents one of the first applications of optically excited micromachined silicon resonators for harsh environments. The resonator is mounted inside a silicon tube; when the tube is deformed the resonance frequency changes to give a signal proportional to the applied pressure. Excitation is supplied by intensity-modulated laser light through a single-mode fibre and the oscillation frequency is detected interferometrically via the same fibre. (Author abstract) 1 Ref.

**1992 Title:** PATTERN RECOGNITION BASED BICOHERENCE ANALYSIS OF VIBRATIONS FOR BEARING CONDITION MONITORING.

**Author:** Li, C. James; Ma, J.; Hwang, B.; Nickerson, G. W.

**Source:** Sensors, Controls, and Quality Issues in Manufacturing American Society of Mechanical Engineers, Production Engineering Division (Publication) PED v 55. Publ by ASME, New York, NY, USA p 1-11

**Abstract:** For automatic detection/diagnosis of localized defects in rolling element bearings, a pattern recognition analysis scheme based on features extracted from bearing vibrations using bispectral analysis is developed. Features are extracted using the bicoherence spectrum to detect the sum frequency components of bearing characteristic defect frequencies and their harmonics. Employing these features, a linear discriminant classifier has been established to detect localized defects on a roller and outer-race of a bearing. Experimental results show that the bispectral analysis for the detection of localized defects of rolling element bearings is very effective even

when power spectral analysis fails to distinguish the abnormal states from the normal one. (Author abstract) 19 Refs.

- 1992 Title:** CHARACTERIZATION OF A NEW DEVICE FOR PRESSURE SENSING: THE AlGaAs/GaAs TEGFET.

**Author:** Lorenzini, P.; Dusseau, J. -M.; Robert, J. L.; Mosser, V.; Contreras, S.

**Source:** Sensors and Actuators, A: Physical v 33 n 1-2 May p 53-56

**Abstract:** Due to the specific properties of substitutional donor impurities in GaAlAs compounds, a deionization of the Si donor occurs when pressure is applied to a sample having an Al content in the range 0.25-0.4. As this phenomenon has a high-pressure sensitivity, we propose a new kind of active pressure sensor based upon the use of two-dimensional AlGaAs/GaAs heterostructures (transistor TEGFET). In such a transistor, we show that pressure and gate voltage play a similar role. The transistor sensibility to the pressure depends on its working range. Our measurements show that the sensitivity in the saturation region, with  $V//G$  (gate voltage) near to  $V//T$  (threshold voltage), is larger than the sensitivity in the linear regime with  $V//G$  greater than  $V//T$ . (Author abstract) 8 Refs.

- 1992 Title:** A HIGH PRECISION, SIX DEGREE-OF-FREEDOM, SINGLE-SIDED NONCONTACT, OPTICAL SENSOR SUITABLE FOR ASSEMBLY AUTOMATION.

**Author:** Mancevski, V.; Qian, D.; Wang, W., Narayanan, C., Busch-Vishniac, I.; Buckman, A.B.

**Source:** Proceedings of the 1992 NSF Design and Manufacturing Systems Conference p 1613.

**Abstract:** The ultimate goal of this research is the development of a six degree-of-freedom optical sensor capable of submicron precision which can be located entirely on one side of a target. The sensor is divided into two sections, an out-of-plane displacement sensing subsystem, using a narrow beam light source and one or two lateral effect photodiodes, and an in-plane coordinate sensing subsection using a wide beam light source and one or two lateral effect photodiodes. In this paper we discuss the out-of-plane measurement section of the sensing system. Preliminary results show a high degree of linearity over a wide range. The successful demonstration of this sensor will be important in the automated assembly of parts, where it is often necessary to have multiple coordinate information for real time control.

- 1992 Title:** HIGH-SPEED SENSITIVE THERMOVOLTAIC IR DETECTORS.

**Author:** Marchetti, S.; Simili, R.

**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 389-392

**Abstract:** In this work we report the optimized thermoelectric response of Sb anisotropic films evaporated on n-Si thin substrates. By using a suitable film thickness, up to  $150 \mu V/W$  (30ns) direct response can be observed at  $10 \mu m$ , which is 10-100 times larger than for the best pyroelectric detector. By

using an Si-Sb-nSi wafer a fast response is observed (ns), about 10 times longer than for commercial photon-drag detectors.

- 1992 Title:** FIBER OPTIC SENSORS FOCUS ON SMART SYSTEMS.  
**Author:** Measures, Raymond M.; Liu, Kexing  
**Source:** IEEE Circuits and Devices Magazine v 8 n 4 Jul p 37-46  
**Abstract:** Materials with structurally integrated fiber-optic sensors, the first step toward smart structures, which continuously monitor their own vibration, internal strain and deformation, temperature, and structural integrity are described. It is shown that the Fabry-Perot fiber-optic strain sensor has capabilities that far exceed those of conventional foil strain gauges, which holds the promise of responding to acoustic emission signals while simultaneously tracking the high loads likely to be encountered in practical structures such as aircraft wings. The same sensing system may be able to monitor the degree of cure during fabrication of thermoset composite structures. The fabrication and characterization of such all-fiber, intrinsic Fabry-Perot strain sensors are discussed. Passive and active homodyne signal recovery techniques used in the fiber-optic sensor systems are also described. 12 Refs.
- 1992 Title:** POLYCHROMATIC BIREFRINGENCE SENSING FOR OPTICAL FIBRE MONITORING OF SURFACE STRAIN.  
**Author:** Murphy, M. M.; Jones, G. R.  
**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 691-695  
**Abstract:** A novel integrated optical fibre strain sensor is described which was designed with the aid of a computational model. The system uses the concept of chromatic modulation which is produced by spectral changes induced by controlled birefringence. The sensor has demonstrated good strain sensitivity and with a modular construction exhibited suitable ruggedness for the industrial environment. The chromatic sensing technique has enabled intensity insensitive measurements to be made.
- 1992 Title:** EVALUATION OF COMMERCIAL FIBER OPTIC SENSORS IN A MARINE BOILER ROOM.  
**Author:** Musselman, Martin L.  
**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 1589. Publ by Int Soc for Optical Engineering, Bellingham, WA, USA p 56-57  
**Abstract:** The Naval Research Laboratory (NRL) established a Navy Potential Contractor Program (NPCP) agreement with Newport News Shipbuilding and Drydock Company (NNS) to install and evaluate Navy-supplied sensors in an operational environment. The purpose here was to not only assess the sensors performance in the real world, but to assess the installation difficulties. An important product of this task will be a comprehensive shipyard recommendation of specific sensing applications for which these sensors appear to offer an advantage over conventional sensors. This paper



describes the installation and operation of three totally dissimilar fiber optic sensing techniques in a fully operational, fossil-fuel, steam- generating plant, the NNS barge Nancy Lee. Nancy Lee is used to provide steam on an ad hoc basis to ships under construction or overhaul when it is not feasible to use the ship's own steam generating plant. Her normal operational mode makes Nancy Lee a particularly well- suited platform for sensor evaluation. Unlike normal steam plants that only 'go down' for maintenance or repairs, Nancy Lee goes up and down as required and thus provides thermal and mechanical stresses on sensors that would not be seen in years of operation in a conventional steam plant. All sensors measured the parameters they were designed for, each within its own limitations.

**1992 Title:** A LIQUID SHEAR-STRESS SENSOR FABRICATED USING WAFER BONDING TECHNOLOGY.

**Author:** Ng, Kay-Yip; Shajii, Javad; Schmidt, Martin A.

**Source:** Transducers '91 91 Int Conf Solid State Sens Actuators. Publ by IEEE, IEEE Service Center, Piscataway, NJ, USA (IEEE cat n 91CH2817-5) p 931-934

**Abstract:** The authors report on the fabrication and testing of a microfabricated silicon floating-element (120  $\mu\text{m}$  multiplied by 140  $\mu\text{m}$ ) shear-stress sensor designed to detect high shear stresses (1-100 KPa) in fluid environments. Wafer bonding technology is used to produce a thin (5  $\mu\text{m}$ ) dielectrically isolated silicon layer (allowing piezoresistive transduction in a half-bridge readout scheme) which is further processed to develop the floating-element sensor. The authors describe the details of the sensor fabrication, modeling of the sensor response, and the results of testing. There is good agreement between the modeled response of the sensor and the experimental data, and the sensor has also maintained its structural integrity under severe conditions. 7 Refs.

**1992 Title:** NEW TACTILE SENSOR LIKE THE HUMAN HAND AND ITS APPLICATIONS.

**Author:** Omata, Sadao; Terunuma, Yoshikazu

**Source:** Sensors and Actuators, A: Physical v 35 n 1 Oct p 9-15

**Abstract:** This paper describes the development of a new type of tactile sensor which is designed to operate with a piezoelectric element employed as the sensor. Conventional tactile sensors, which consist of a strain gauge, conductive elastomer and piezoelectric polymer film, are confined solely to data acquisition relating to pressure or force. However, the new sensor proposed here is able to detect, very much like the human hand, the hardness and/or softness of an object. Several experiments have been carried out to investigate its possible applications in robotics and medicine. It is demonstrated that the visualization of tactile sensory performance using the new sensor is most useful in a robotics application; the sensor is also able to detect the hardness of an extraneous substance and that of skin. (Author abstract) 8 Refs.

**1992 Title:** SIMPLE FIBRE OPTIC SENSOR FOR MEASUREMENT OF VIBRATIONAL FREQUENCIES.

**Author:** Philp, WR; Booth, DJ; Shelamoff, A; Linthwaite, MJ

**Source:** Measurement Science & Technology v 3 n 6 Jun p 603-606

**Abstract:** A non-contact non-interferometric fibre optic vibration sensor is described which is constructed from a 50/125  $\mu\text{m}$  multimode communication grade directional coupler, a modulated 820 nm LED and a PIN photodiode module. The sensing fibre is one arm of the directional coupler. The sensor is designed to detect small proximity variations between an unprepared reflective surface and the end of the sensing fibre. Vibrations of amplitude 1  $\mu\text{m}$  for mirrored surfaces and 4  $\mu\text{m}$  for unpolished aluminium can be detected for a sensor located approximately 50  $\mu\text{m}$  from the vibrating surface. The sensor output is reasonably linear for vibration amplitudes up to about 0.2 mm. The sensor uses synchronous detection circuitry based on common, low cost integrated circuits to improve the output signal-to-noise ratio by a factor of ten. The design of the vibration sensor is described in sufficient detail for it to be easily reconstructed at minimum expense. (Author abstract) 7 Refs.

**1992 Title:** TEMPERATURE CHARACTERISTICS OF AN ALL-FIBRE OPTICALLY ADDRESSED SILICON MICRORESONATOR SENSOR.

**Author:** Rao, Y. J.; Walsh, D.; Uttamchandani, D.; Culshaw, B.

**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 706-709

**Abstract:** A compact sensor head for all-fibre optically addressed silicon microresonator sensors for pressure and temperature measurements has been developed and demonstrated. The temperature characteristics in such a sensor system have been measured and analysed. It has been determined from the observed results that the additional thermal expansion of the substrate used to fix the silicon bridge results in a decrease of the overall temperature sensitivity of resonant frequency. The overall temperature coefficient of resonant frequency changes from a positive to a negative value and gradually reduces as temperature increases. AA 7.

**1992 Title:** TACTILE IMAGING.

**Author:** Regtien, P. P. L.

**Source:** Sensors and Actuators, A: Physical v 31 n 1-3 pt 3 Mar p 83-89

**Abstract:** Many physical principles have been explored for the realization of tactile sensor: resistive, inductive, capacitive, optoelectric, magnetic, piezoelectric and electroacoustic principles, in a variety of configurations. A key problem in the design of a tactile image is the taxel density, determining the spatial resolution of the device. This paper reviews the various strategies and principles, discusses some particular design problems and gives the state of the art in tactile sensing. (Author abstract) 14 Refs.

**1992 Title:** MEASURING ENGINE OIL FILMS.

**Author:** Richardson, Dana E.; Borman, Gary L.

**Source:** Automotive Engineering (Warrendale, Pennsylvania) v 100 n 1 Jan p 15-18

**Abstract:** A new method, using fiber optics and laser-induced fluorescence, was developed for measuring the oil films on engine cylinder walls. It offers improved understanding of oil transport and consumption. The development of the method for using laser-induced fluorescence and fiber optics consisted of a series of steps. First, static tests were run to characterize the fluorescent signal and the effects of different parameters on the fluorescence. Then a simple dynamic test rig was used to verify that the system could measure thin oil films under dynamic conditions and varied conditions. Ultimately, the fiber optics were mounted in an engine to characterize oil flow. (Edited author abstract)

**1992 Title:** SMART ACCELEROMETER WITH ON-CHIP ELECTRONICS FABRICATED BY A COMMERCIAL CMOS PROCESS.

**Author:** Riethmuller, W.; Benecke, W.; Schnakenberg, U.; Wagner, B.

**Source:** Sensors and Actuators, A: Physical v 31 n 1-3 pt 3 Mar p 121-124

**Abstract:** Piezoresistive accelerometers with a monolithically integrated operational amplifier were produced, the fabrication process based on a commercial 3  $\mu$ m CMOS process. The mechanical structures were realized using wet anisotropic etching of silicon with KOH and the electrochemical etch-stop at p-n junctions. Measurements show that the integration of these necessary micromachining process steps into the IC process do not influence the parameters of the electronic devices. Also, the parameters of the mechanical structures are comparable to discrete devices. The realization of applicationspecific smart mechanical sensors and actuators using a standard CMOS process is now possible. (Author abstract) 19 Refs.

**1992 Title:** MICROMACHINED SENSOR STRUCTURES WITH LINEAR CAPACITIVE RESPONSE.

**Author:** Rosengren, Lars; Soderkvist, Jan; Smith, Leif

**Source:** Sensors and Actuators, A: Physical v 31 n 1-3 pt 3 Mar p 200-205

**Abstract:** Capacitive membrane-type pressure sensors normally have nonlinear pressure-capacitance relationships, implying the need for sophisticated electronics. Various capacitive pressure sensor structures with improved linearity are suggested in this article. These include membranes that touch the bottom of the cavity, corrugated or thinned membrane edges with stiffened membrane centers, as well as a sensor structure with a double-comb design. The design possibilities increase with these methods. Most work was carried out with the help of finite element analysis (FEA). Pressure sensors have been manufactured based on the FEA simulations, and the experiments verify the calculations. The results show very promising linearity properties, with nonlinearity less than 1% and sensitivities around 10 pF/bar. Weaknesses introduced in the membraned can improve performance if they are located correctly. (Author abstract) 6 Refs.

- 1992 Title:** CAPACITIVE OIL DETERIORATION SENSOR.  
**Author:** Saloka, George S.; Meitzler, Allen H.  
**Source:** SAE Technical Paper Series. Publ by SAE, Warrendale, PA, USA, 910497. 10p  
**Abstract:** There is a need for sensors that respond to chemical and physical properties of engine oil. In response to this need, an experimental design of an engine-mounted, capacitive sensor has been developed to monitor changes in the dielectric constant of the engine oil. The sensing element is a small, air-gap capacitor that is mounted in a spacer ring that fits between the oil filter and the engine block. Embedded in the same spacer ring is the associated circuitry. Experiments have been carried out with experimental capacitive oil sensors mounted on engines using a typical fully-formulated, factory-fill oil. The oil dielectric constant initially decreases and is less than the starting value while the anti-oxidant additives are active. After about 1600 km, the antioxidant additives become sufficiently depleted to allow oxidation products to accumulate and for the oil dielectric constant to increase at a steady rate of about 1% per 1000 km. (Author abstract) 8 Refs.
- 1992 Title:** SILICON SUBMINIATURE MICROPHONE BASED ON PIEZORESISTIVE POLYSILICON STRAIN GAUGES.  
**Author:** Schellin, R.; Hess, G.  
**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 555-559  
**Abstract:** A silicon subminiature microphone, based on the piezoresistive effect in polysilicon using only one chip, is proposed. The acoustic sensor is fabricated by a technique that is compatible with a slightly modified CMOS process also using a standard micromechanical fabrication technology. The main production steps will be described, including the design and the fabrication of the sensor. Experimental results of the piezoresistive coupling factors and the temperature dependence of the polysilicon resistors are given. Measured results of the airborne sound sensitivity are about minus 92 dB/Pa. The frequency response is nearly flat with deviations of about plus or minus 3 dB from 100 Hz to 5 kHz and with a resonance at 10 kHz.
- 1992 Title:** SELECTIVE DETECTION OF ORGANIC MOLECULES WITH POLYMERS AND SUPRAMOLECULAR COMPOUNDS: APPLICATION OF CAPACITANCE, QUARTZ MICROBALANCE AND CALORIMETRIC TRANSDUCERS.  
**Author:** Schierbaum, K. D.; Gerlach, A.; Haug, M.; Gopel, W.  
**Source:** Sensors and Actuators, A: Physical v 31 n 1-3 pt 3 Mar p 130-137  
**Abstract:** Different 'prototype' organic coatings were used for three different transducers with the aim of optimizing the selective detection of organic molecules. The different thermodynamically and kinetically controlled sensor parameters were obtained from capacitance, quartz microbalance and calorimetric transducers. The results are discussed in the framework of different interaction mechanisms which occur in the detection of one organic

gas component with its specific molecular weight, dielectric constant or heat of interaction. (Author abstract) 17 Refs.

**1992 Title: APPLICATION-SPECIFIC DESIGN OF A PIEZOELECTRIC CHEMOSENSOR ARRAY.**

**Author:** Schmautz, A.

**Source:** Sensors and Actuators, B: Chemical v B6 n 1-3 Jan p 38-44

**Abstract:** A piezoelectric quartz sensor array with non-selective but different sensitive coating materials is used for the analysis of anaesthetic gases. Several gas-sensitive quartz resonators can be composed into an array and the sensor signals can be handled by pattern-recognition (PARC) methods. The steady-state single-sensor signals and the dynamic responses of the sensors can be calculated and processed using the partition coefficient and the heat of adsorption, respectively. Identification of different narcotics like halothane, enflurane, isoflurane and sevoflurane is achieved by classification of the gases in the discriminant plane with PARC methods. The sensitivity and selectivity of a piezoelectric gas sensor can be influenced by the selection of the absorptive coating materials. Substances used as gas chromatographic stationary phases are found to be useful as gas-sensitive coatings for the quartz resonators. Together with the pattern-recognition method, the above-mentioned parameters describing the function of the coating can be used, e.g., to increase the number of gases that can be identified with the chemosensor array. To achieve different cross-sensitivities of a redesigned sensor array determined by back-transformation of the signal patterns from the feature space, the gas chromatographic coating materials can be selected by means of the partition coefficient value. With this parameter an optimal design of the piezoelectric chemosensor array with respect to sensitivity and selectivity is possible. (Author abstract) 16 Refs.

**1992 Title: SMART CMOS CAPACITIVE PRESSURE TRANSDUCER WITH ON-CHIP CALIBRATION CAPABILITY.**

**Author:** Schnatz, F. V.; Schoeneberg, U.; Brockherde, W.; Kopystynski, P.; Mehlhorn, T.; Obermeier, E.; Benzel, H.

**Source:** Sensors and Actuators, A: Physical v 34 n 1 Jul p 77-83

**Abstract:** A capacitive pressure sensor with CMOS switched-capacitor circuitry for on-chip signal conditioning is introduced. It features differential generation and treatment of pressure-induced capacitance changes to suppress various parasitic effects. A digital calibration capability is provided for sensitivity adjustment and for temperature compensation. The fabrication of the transducer is largely congruent with a standard n-well CMOS process. The paper explains the function of the circuitry and its implications for the sensor design and presents experimental results obtained in testing the various components of the transducer as well as the overall sensor system. (Author abstract) 4 Refs.

**1992 Title:** ANALYSIS ON TWIN-MASS STRUCTURE FOR A PIEZORESISTIVE ACCELEROMETER.

**Author:** Shen, Shaoqun; Chen, Jian; Bao, Minhang

**Source:** Sensors and Actuators, A: Physical v 34 n 2 Aug p 101-107

**Abstract:** A novel mechanical structure for a piezoresistive silicon accelerometer is described and analysed. This structure consists of two seismic masses instead of one and five beams instead of the two or four in existing designs. The single sign and uniform profile of the stress at the central beam makes it ideal for locating sensing elements. Analytical analyses show that no lateral sensitivity can be caused by an acceleration in the beam direction and the sensitivity caused by a lateral acceleration vertical to the beam direction is also eliminated to the first order of approximation by a symmetrical design of the sensing elements. Both the normal sensitivity and basic resonance frequency of the structure are in between those of the cantilever beam structure and the double-side-supported structure, but the figure of merit, i.e., the sensitivity frequency product, is higher for the two-mass structure than for the other two structures. (Author abstract) 7 Refs.

**1992 Title:** ON THE CORRELATION BETWEEN THE VIBRATION MEASUREMENT AND TOOL WEAR IN TURNING.

**Author:** Sokolowski, Andrzej; Liu, Jia-Jay; Kosmol, Jan

**Source:** Flexible Automation 1992 Proc 92 Jpn USA Symp Flexible Autom. Publ by ASME, New York, NY, USA p 1075-1081

**Abstract:** The paper describes an investigation on using the vibration of selected machine tool elements as a means to detect the cutting tool conditions. At the first stage of investigation, an analysis of the dynamic features of the tool shank - holder system was done. Then, the measurements for different cutting conditions and parametrically changed tool flank wear were carried out. The spectral characteristics of the vibration velocity were used as the basis to determine relationships between the tool wear factor (VB) and the amplitude of vibration. Also, the influence of the cutting parameters on the observed values was analyzed. The strong correlation between the tool flank wear and the amplitude of vibration velocities has been shown and the sensitivity of observed values on changes in cutting parameters has been discussed. (Author abstract) 17 Refs.

**1992 Title:** NON-CONTACTING TORQUE MEASUREMENT BY A MODIFIED MOIRE FRINGE METHOD.

**Author:** Spooncer, R. C.; Heger, R.; Jones, B. E.

**Source:** Sensors and Actuators, A: Physical v 31 n 1-3 pt 3 Mar p 178-181

**Abstract:** An optical torque sensor has been demonstrated which uses a modified moire fringe method of measuring torque in a rotating shaft. The system utilizes two circular gratings mounted concentrically at separate points on the shaft; one grating is ruled radially, and the second has rulings which are tangential to a small central generating circle. Circular fringes are formed which move radially as the angular displacement between the gratings

changes. A model has been developed relating the radial movement of a selected fringe to the twist in the shaft. Measurement of fringe movement on a test rig showed adherence to the model within plus or minus 1%. (Author abstract) 4 Refs.

- 1992 Title: ON INITIAL FAULT DETECTION OF A TAPERED ROLLER BEARING. FREQUENCY DOMAIN ANALYSIS.

Author: Su, Y. -T.; Lin, S. -J.

Source: Journal of Sound and Vibration v 155 n 1 May 22 p 75-84

Abstract: The frequency characteristics of vibration for a defective bearing subjected to various loadings are investigated. The vibration model developed by McFadden and Smith is extended to describe the bearing vibration induced by a single defect, or by multiple defects located at arbitrary positions, of a bearing under diverse loadings. On the basis of the model, the vibration spectrum is a discrete one with a pattern of 'equal frequency spacing distribution'. In the demodulated spectrum, there are peaks at the defect frequency and its harmonics. Around each peak, there are side bands associated with the periodic properties of the loadings and the transmission path. The validity of the analytical study is confirmed by an extensive evaluation of experiments. (Author abstract) 9 Refs.

- 1992 Title: THE DEVELOPMENT AND USE OF THIN FILM THERMOCOUPLES FOR CONTACT TEMPERATURE MEASUREMENT.

Author: Tian, X., Kennedy, F.E., Deacutis, J.J.; Henning, A.K.

Source: Tribology Transactions v 35 3 p 491-499.

Abstract: A procedure was developed for producing thin film thermocouples (TFTC) on the contact surface of sliding mechanical components. The thermocouple devices were made from thin films of vapor-deposited copper and nickel. The measuring junctions of the thermocouples were approximately 2  $\mu\text{m}$  thick and between 80  $\mu\text{m}$  and 300  $\mu\text{m}$  across. The TFTC devices were found to have extremely rapid ( $< 1 \mu\text{s}$ ) response to a sudden temperature change and did not significantly disturb the heat flow from the sliding contact. It was found necessary to sandwich the TFTC between thin films of a hard, non-conducting ceramic ( $\text{Al}_2\text{O}_3$  in the current work) to insulate the thermocouple electrically from the substrate and protect it during sliding.

Thin film thermocouple devices were applied to the measurement of sliding surface temperatures in two cases, oscillatory dry sliding of a polymer pin on a flat surface, and uni-directional dry sliding of a ring over a flat pin surface. Results from the tests verified theoretical predictions.

- 1992 Title: OPTICAL PRESSURE SENSORS BASED ON SEMICONDUCTOR QUANTUM WELLS.

Author: Trzeciakowski, W.; Perlin, P.; Teisseyre, H.; Mendonca, C. A.; Micovic, M.; Ciepielewski, P.; Kaminska, E.

Source: Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 632-638

**Abstract:** The luminescence of layered GaAs/AlGaAs MQW (multiple quantum wells) grown by molecular beam epitaxy has been studied. Under hydrostatic pressure the narrow excitonic line shifts to higher energies; thus it can be used to calibrate the pressure. The shift of the line is about 11 meV/kbar and does not seem to vary with temperature. Samples with different widths and depths of the wells have been investigated in order to increase the intensity of the line. Measurements are performed at various temperatures (from 12 to 400 K), powers and polarizations of the exciting light. The upper pressure limit of the device is determined by the change from direct to indirect optical transitions. The comparison with ruby fluorescence shows that our MQW sensors are over an order of magnitude more accurate in the 0-40 kbar pressure range.

**1992 Title:** PIEZORESISTIVE ACCELERATION SENSOR FOR AUTOMOTIVE APPLICATIONS.

**Author:** Tsugai, Masahiro; Bessho, Mikio; Araki, Toru; Onishi, Masayoshi; Sesekura, Takashi

**Source:** SAE Technical Paper Series. Publ by SAE, Warrendale, PA, USA, 920476 p 41-46

**Abstract:** A small, low-cost piezoresistive acceleration sensor suitable for automotive applications such as advanced braking control and suspension control systems has been developed. A piezoresistive semiconductor sensor has such advantages as high output linearity, long-term output repeatability and DC response a piezoelectric sensor doesn't feature. One drawback, however, is that piezoresistive characteristics are quite temperature sensitive: Such that temperature dependence of DC offset and span have to be compensated with a certain electrical circuit. With 1 mV/Vs/G, the low sensitivity of the acceleration sensor [Vs:bridge voltage, G:gravitational acceleration], the temperature shift of DC offset represented in terms of the sensitivity, becomes relatively high. For this reason, we have used a new temperature compensation circuit including a voltage supply sensitive to temperature and a compensation resistor, achieving about 3% offset temperature error per 1.5G full scale in the operating temperature range from minus 30 degree C to 85 degree C. (Author abstract) 7 Refs.

**1992 Title:** SILICON INTEGRATED MINIATURE CHEMICAL ANALYSIS SYSTEM.

**Author:** van der Schoot, Bart, H.; Jeanneret, Sylvain; van den Berg, Albert; de Rooij, Nico, F.

**Source:** Sensors and Actuators, B: Chemical v B6 n 1-3 Jan p 57-60

**Abstract:** Piezoelectrically driven micromachined silicon pumps are shown to have excellent characteristics for application in miniaturized chemical analysis systems. A system is demonstrated using two micro pumps and a separate glass flow-through cell with a potassium-sensitive ISFET. The measurement protocol is such that the sample solution enters the detector but does not pass the sensitive pump valves, thus improving the practical



applicability of the system. During its operation, the sensor is continuously calibrated with a very low consumption of calibrating solution. With a measurement rate of four samples per minute, the use of calibrant is less than 3 ml/h. (Author abstract) 2 Refs.

**1992 Title: FLUORESCENT SENSOR AS AN ENGINE OIL QUALITY INDICATOR.**

**Author:** Vinas, M. H.; Murciano, E. M.; Montoro, T.; Escudero, J. L.

**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 1648. Publ by Int Soc for Optical Engineering, Bellingham, WA, USA p 238-247

**Abstract:** In this work, a spectroscopic method to measure the degradation degree of paraffinic mineral oils is proposed. The behavior of some molecules (indoles) in solution versus their surrounding environment (solvent polarity and viscosity) is the basis of the method. Experimental results obtained for VESTAN oil, confirming this theoretical scheme, are presented. (Author abstract) 13 refs.

**1992 Title: MONOLITHIC FLOW SENSOR FOR MEASURING MILLILITRE PER MINUTE LIQUID FLOW.**

**Author:** Yang, Canqian; Soeberg, Henrik

**Source:** Sensors and Actuators, A: Physical v 33 n 3 Jun p 143-153

**Abstract:** A flowmeter based on a monolithic integrated flow sensor has been developed for measuring liquid flows as small as 0.1 ml/min in microchannels. The flowmeter is able to operate in thermal transit-time mode and thermal dilution mode. Diodes on the silicon chip are used both as the heating device and as the temperature detectors. When operating in thermal transit-time mode, the flowmeter has an accuracy better than 0.2% (at a flow rate of 0.2 ml/min) and a 90% response time less than 1 s. While operating in thermal dilution mode, the flowmeter has an accuracy of about 1%, but features an excellent dynamic performance with a minus 3 dB frequency cutoff up to 5 Hz. A dynamic model has also been developed for the interpretation of the mechanism of the flow sensor and for the calibration of the flowmeter. Simulation based on the model shows good agreement with the experimental results. The flowmeter will be used to monitor and control the liquid flow in FIA (flow injection analysis) systems. (Author abstract) 13 Refs.

**1992 Title: INTRINSIC OPTICAL FIBRE SENSOR FOR MONITORING ACOUSTIC EMISSION.**

**Author:** Zheng, S.X.; McBride, R.; Barton, J.S.; Jones, J.D.C.

**Source:** Sensors and Actuators A 31 p 110-114.

**Abstract:** A novel intrinsic optical fibre sensor for detection of acoustic emission (AE) has been designed, built and tested. This sensor is intended for use in monitoring machine tool wear. An optical fibre is held between the transducer backing and the surface being probed. The coupling of AE waves

through the fibre into the backing causes a phase change in the light transmitted by the fibre. This phase change is detected using a Mach-Zehnder interferometer, locked in quadrature with a phase servo. Acoustic emission during cutting is conveyed to the sensing fibre on the machine bed via either the tool or workpiece. Sensing of AE may then yield information on the state of wear of the tool.

**1992 Title: CAPACITIVE TACTILE SENSOR FOR SHEAR AND NORMAL FORCE MEASUREMENTS.**

**Author:** Zhu, F.; Spronck, J. W.

**Source:** Sensors and Actuators, A: Physical v 31 n 1-3 pt 3 Mar p 115-120

**Abstract:** This paper describes a new capacitive tactile sensor for shear and normal force measurements. The spatial sampling principle has been applied to measure the capacitance values efficiently and to transfer the spatial capacitance distribution into the time domain. The shear and normal forces are determined by measuring variations in the phase and amplitude of the output signal, respectively. A first experimental model of the sensor shows a resolution of 0.05 N over the range of 10 N for both shear and normal force measurements. (Author abstract) 7 Refs.

**1992 Title: DYNAMIC PROPERTIES OF PRESSURE SENSORS BASED ON ALGAAS FILMS.**

**Author:** Zilionis, S.; Pyragas, K.; Tautvaisas, G.

**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 622-627

**Abstract:** The dynamic properties of pressure transducers using oil-filled cells confined by the thin stainless steel diaphragm to protect the sensing element from aggressive media have been investigated. To obtain the natural frequencies of the protecting diaphragm and the frequency response characteristic of the transducer, an equation of the diaphragm oscillatory motion under the influence of the liquid in the cell has been solved analytically. It is found that: (i) in the frequency range up to 500 kHz, the frequency response characteristic of the transducer depends only on symmetric oscillatory modes of the protecting diaphragm; (ii) under certain conditions, the influence of the liquid in the cell increases the frequency of the lowest symmetric mode of the diaphragm by a factor of 3.4; (iii) resonances of the lowest modes can be made very narrow and, in the case of a viscous liquid, can be eliminated. It is demonstrated that the transducers using AlGaAs semiconductor pressure sensors and this type of media-separating housing can be manufactured with natural frequencies up to 300 kHz.

**1992 Title: EFFECT OF PROCESS PARAMETER VARIATION ON POLYSILICON TEMPERATURE TRANSDUCER CHARACTERISTICS.**

**Author:** Zucker, O.; Langheinrich, W.; Meyer, J.

**Source:** Sensors and Actuators, A: Physical v 32 n 1-3 Apr p 419-422

**Abstract:** Polysilicon layers for application in temperature sensors have been investigated. Hence the characteristics of polysilicon resistors as a function of process parameter variation have been studied. Continuing our previous work, the effect of annealing temperature and time on the thermal behaviour of polysilicon layers is shown in this paper. Also a pre-annealing step preceding the implantation of the dopant has been included in our experiments and the results of this investigation are discussed. It is then shown how layer thickness affects the temperature characteristics of polysilicon meanders. Finally, the characteristics of the temperature transducer of our developed multifunctional sensor are described.

**1991 Title:** SILICON CAPACITIVE PRESSURE TRANSDUCER WITH INCREASED MODULATION DEPTH.

**Author:** Artyomov, V. M.; Kudryashov, E. A.; Shelenshkevich, V. A.; Shulga, A. I.

**Source:** Sensors and Actuators, A: Physical v 28 n 3 Aug p 223-230

**Abstract:** Implementing the potentialities of silicon capacitive pressure sensors requires the solution to a number of design-technology and structure-circuitry problems. This work demonstrates the application of three-electrode capacitive transducers in silicon capacitive pressure sensors. IC technology is shown to provide the best possibility for fabricating three-electrode capacitive transducers with linear dependence of relative impedance versus the diaphragm deflection and, hence, versus applied pressure, the electrodes being flat. It is proposed to position a movable electrode on the diaphragm. It is shown that the real dependence of the relative impedance versus applied pressure in the case of capacitive sensors with a plane diaphragm can be approximated by a straight line with sufficient precision. The area of the electrodes being 0.25 times the area of the diaphragm, the approximation error is less than 1%, while the relative deflection of the centre of the diaphragm varies from minus 1.0 to 0.8. The sensitivity in this case is only 15% less than the highest possible one for capacitive transducers with flat electrodes. When the relative deflection of the centre of the diaphragm varies in the ranges minus 1.0-0 and 0-0.3, the approximation error is less than 0.2%. Experimental results are in good agreement with a theoretical analysis of silicon sensors with plane diaphragms. (Author abstract) 8 Refs.

**1991 Title:** DEVELOPMENT OF QUARTZ CRYSTAL OSCILLATORS FOR UNDER-LIQUID SENSING.

**Author:** Barnes, Christopher

**Source:** Sensors and Actuators, A: Physical v 29 n 1 Sep p 59-69

**Abstract:** A brief history of crystal sensing techniques is presented. Simple resonator equivalent circuits are outlined and expanded upon for cases of crystal immersion in liquids. Conditions for oscillation and choice of appropriate oscillator are discussed. Several well-known recently published sensor oscillator circuits are briefly reviewed and some suggestions for improvements are made. Details are given of two new oscillator circuits

developed and employed by the author. Uniquely, these new circuits allow total immersion of the exposed crystal plate in hitherto impossible media, such as viscous liquids of viscosity up to 40 cP and in electrolytes and buffers of several millimolar ionic strength. Finally, suggestions for gain and stability control of oscillators in practical 'under-liquid' sensing situations are made in relation to the future potential of these techniques. (Author abstract) 18 Refs.

- 1991 Title:** DYNAMOMETRICAL SENSORS. (MANY) PROBLEMS, (SOME) SOLUTIONS.

**Author:** Bethe, Klaus

**Source:** Sensors and Actuators, A: Physical v 26 n 1-3 Mar p 285-293

**Abstract:** Force and force-related 'dynamometrical sensors' rely on the springbalance or, in special cases, on the compensation principle. Although they are commercially available in an enormous variety, these sensors still suffer from a number of metrological and applicational drawbacks. In addition, sensors for consumer applications have to be considerably reduced in price. This latter aim requires a narrow-tolerance batch-production, not only for Si, but also for metal-based sensors for example. This situation is briefly commented on and illustrated by some new solutions: a compact load cell (FEM), two consumerproduct sensors (one three-dimensional, one based on sheet metal), CA digital trimming, creep/sapphire sensor, electrostatically compensating sensors and a general look at nonlinear (progressive spring) dynamometrical sensors and their advantages. (Author abstract)

- 1991 Title:** ADHESIVE AND ABRASIVE WEAR STUDIES USING ACOUSTIC EMISSION TECHNIQUES.

**Author:** Boness, R. J.; McBride, S. L.

**Source:** Wear of Materials: International Conference on Wear of Materials v 1. Publ by ASME, New York, NY, USA p 425-432

**Abstract:** This paper is concerned with the measurement and subsequent analysis of acoustic emission signals from lubricated sliding contacts. The results show that the time dependent nature of the acoustic signal is able to detect the presence of wear reducing additives and the predominant wear process occurring. Further third body abrasive wear tests show that both wear and acoustic emission signals increase with alumina particle concentration added to the lubricant. A direct empirical relationship between integrated rms signal and the wear volume removed from the test ball in a ball-on-cylinder test apparatus has been obtained. (Author abstract)

- 1991 Title:** IN LUBRO STUDIES OF LUBRICANTS IN EHD CONTACTS USING FTIR ABSORPTION SPECTROSCOPY.

**Author:** Cann, P.M. and Spikes, H.A.

**Source:** Tribology Transactions v 34 2 p 248-356.

**Abstract:** Research into the physical and chemical processes occurring within lubricated concentrated contacts has traditionally been limited by the necessity

to observe events out-of-contact, or under simulated conditions. This paper describes the application of a new technique involving infrared microreflection absorption spectroscopy. The method is applied to the direct determination of the conditions of pressure experienced by lubricants in contacts, to the formation of antiwear films by phosphorus additives and to the study of the alignment of molecules, including viscosity index improvers in contacts.

- 1991 Title:** EPITAXIAL SILICON ON ZIRCONIA (SOZ) PRESSURE SENSOR  
**Author:** Chen, Qinggui; Wang, Weiyuan  
**Source:** Sensors and Actuators, A: Physical v 28 n 2 Jul p 153-156  
**Abstract:** Using high dielectric strength zirconia as a substrate instead of sapphire, the first SOZ (silicon on zirconia) pressure sensors have been developed. The preliminary results show that without any temperature compensation for zero output and sensitivity, the devices reach a performance similar to that of SOS pressure sensors. (Author abstract) 9 Refs.
- 1991 Title:** IN-PROCESS WORKPIECE TEMPERATURE SENSOR.  
**Author:** Cogdell, J. David  
**Source:** Precision Engineering v 13 n 2 Apr p 135-138  
**Abstract:** Author describes an in-process workpiece temperature sensor and its applications. Potential applications include real-time workpiece temperature measurement and prediction of workpiece thermal damage and growth. The physics of material removal is profoundly affected by thermally activated tribochemical reactions involving the cutting tool, nascent workpiece surfaces in and immediately down-rotation from the workpiece-wheel interface, and the coolant/lubricant (which may be either liquid, gas, or solid). Unwanted thermally activated metallurgical transformation (grinder burn) is a matter of concern in most production grinding operations: workpiece growth caused by increasing bulk temperature during the grinding cycle can make precise dimensional control difficult. Dynamic workpiece temperature measurement could form the basis for a grinder control system (or refinement of an existing system) that would allow significantly increased production and/or improved quality. 8 Refs.
- 1991 Title:** DIFFUSION OF EXTREME PRESSURE-ANTIWEAR ADDITIVES IN OIL MEASURED BY HOLOGRAPHIC INTERFEROMETRY.  
**Author:** Dudler, V.; Cuhe, D.; Egger, G.  
**Source:** Wear v 146 n 1 May 30 p 79-87  
**Abstract:** The diffusion of extreme pressure-antiwear additives in synthetic lubricants has been studied by real-time holographic interferometry. The method and its advantages for the measurement of diffusion in oils are discussed. The diffusion coefficients of three phosphorus-containing molecules, used as model compounds, have been measured between 25 and 100 degree C and very low values for the diffusion coefficients in liquid are reported. The results show that the additive structure has less influence on

the diffusion coefficient than the oil viscosity. The relationship between the diffusion and the viscosity does not follow the Stokes formula and a new approximation is proposed. (Author abstract) 10 Refs.

**1991 Title:** PRESSURE SENSORS MERGE MICROMACHINING AND MICROELECTRONICS.

**Author:** Frank, Randy

**Source:** Sensors and Actuators, A: Physical v 28 n 2 Jul p 93-103

**Abstract:** Sensing system requirements vary considerably from system to system and depend heavily upon the market segment and application: automotive versus industrial, manifold absolute pressure versus blood pressure. Both of these particular examples utilize micromachined silicon and have been the focus of several manufacturers' efforts for the past decade. The experience obtained from supplying these products in volume and working with customers to determine future sensing requirements is leading to new types of sensors and increased integration. This paper will present some of the problems that confront the development and manufacture of more complex silicon structures and integrated control circuits. (Author abstract) 9 Refs.

**1991 Title:** FRONT END CMOS CIRCUIT FOR A FULL-BRIDGE PIEZORESISTIVE PRESSURE SENSOR.

**Author:** Gakkestad, J.; Jakobsen, H.; Ohlckers, P.

**Source:** Sensors and Actuators, A: Physical v 27 n 1-3 May p 859-863

**Abstract:** A CMOS circuit with compensation of the temperature dependency of sensitivity, adjustable voltage excitation and adjustable full-scale output for full-bridge piezoresistive pressure sensors is designed. The circuit requires six external resistors; two of these are used to adjust the temperature coefficient of the excitation voltage to the sensor, two to adjust the level of the excitation voltage and two to adjust the level of the full-scale output. The concept has been tested on SensoNor's SP 81 pressure family. The results show that the sensitivity deviation is reduced from approximately 18 to minus 0.78% in the temperature range minus 40 to plus 100 degree C, and the temperature coefficient of sensitivity is reduced from approximately minus 2300 to minus 53 ppm/ degree C using a straight-line approximation. (Author abstract)

**1991 Title:** SURFACE MICROMACHINED PRESSURE TRANSDUCERS.

**Author:** Guckel, H.

**Source:** Sensors and Actuators, A: Physical v 28 n 2 Jul p 133-146

**Abstract:** Typical IC processing is fundamentally two dimensional; sensors are three-dimensional structures. In surface micromachining, two-dimensional IC processing is extended to sensor structures by the addition of one or more sacrificial layers which are removed by lateral etching. The resulting sensor structures involve the substrate and one or more deposited films which form the intended micromechanical component. The concepts of this type of sensor manufacturing are readily demonstrated by considering

absolute pressure transducers in some detail. Absolute pressure transducers involve a vacuumsealed cavity and a deformation sensing technique. The cavity is formed from the substrate and a low-pressure chemical vapor deposited polycrystalline silicon film. The mechanical properties of this film must be controlled well enough to allow the device to be designed. This implies morphological control during processing. Optimized films which do exhibit controlled compressive or tensile strains exclude oxygen or nitrogen and are therefore not modified by extended hydrofluoric acid etches. Their mechanical behavior is monitored by micromechanical test structures which measure Euler buckling and thereby determine the value of the built-in strain. The cavity vacuum is established by reactive sealing. Long-term vacuum integrity is achieved by a low-stress silicon nitride barrier which also acts as a dielectric isolation barrier. Sensing is accomplished via deposited polysilicon resistors. These devices behave like metal resistors in terms of their temperature coefficient of resistance and noise figure. Their piezoresistive behavior is larger than that of typical metal film structures and smaller than that of single-crystal resistors. Pressure sensors with four diaphragms, two active and two inactive, have been constructed and optimized towards manufacturability. The measured performance is excellent and agrees with the predictions of the design algorithm. (Author abstract) 40 Refs.

- 1991 Title:** PROCEEDINGS OF EUROSensors IV HELD JOINTLY WITH SENSOREN TECHNOLOGIE UND ANWENDUNG.

**Author:** Haerdtl, K. H. (Ed. )

**Source:** Sensors and Actuators, A: Physical v 25 n 1-3 Oct-Jan 1990-1991. Publ by Elsevier Sequoia SA, Subscription Department, Lausanne 1, Switz. 247p

**Abstract:** This volume of the proceedings contains 38 articles devoted to sensors and actuators and their applications. Included are articles related to micromachining, software techniques, packaging and interconnection, bus systems, infrared sensors, optical sensors, fiber sensors, thick film sensors, and one article on humidity sensors.

- 1991 Title:** PROCEEDINGS OF EUROSensors IV HELD JOINTLY WITH SENSOREN TECHNOLOGIE UND ANWENDUNG.

**Author:** Haerdtl, K. H. (Ed. )

**Source:** Sensors and Actuators, A: Physical v 27 n 1-3 May. Publ by Elsevier Sequoia SA, Subscription Department, Lausanne 1, Switz p 555-872

**Abstract:** This volume of the proceedings contains 50 articles dealing with sensors and actuators. Included are articles on micromachined sensors, signal processing, thermal sensors, special sensors, resonant sensors, magnetic sensors and mechanical sensors. The theory and applications of these sensors is stressed.

- 1991 Title:** ACOUSTIC EMISSION MONITORING OF THE WEAR PROCESS.

**Author:** Hanchi, J.; Klamecki, B. E.

**Source:** Wear v 145 n 1 Apr 30 p 1-27

**Abstract:** Acoustic emissions are generated at the sites of the fundamental processes resulting in material wear and so are an attractive possibility for continuously monitoring wear and for basic studies of the wear process. Changes in wear rate and acoustic emission activity were measured across the mild-severe wear transition in the sliding of metals. The intent was to characterize these changes in wear behavior in terms of acoustic emission characteristics and to determine the usefulness of acoustic emission measurements for the study of wear. Experimental results showed that changes in acoustic emission count rates correspond to changing wear rate. Acoustic emission amplitude distributions as well as acoustic emission energy measurements indicated a strong potential for the use of these two parameters in the identification of different modes of failure during the wear process. (Author abstract) 22 Refs.

**1991 Title: ULTRASONIC TRANSDUCERS WITH PIEZOELECTRIC POLYMER FOIL.**

**Author:** Harnisch, F.; Kroemer, N.; Manthey, W.

**Source:** Sensors and Actuators, A: Physical v 26 n 1-3 Mar p 549-552

**Abstract:** The application fields of ultrasonic measurement systems are mainly determined by the properties of ultrasonic transducers. Acoustic features of transducers using piezoelectric polymer foils are considered. The directivity pattern and frequency range can easily be changed by variation of the geometric size and shape of such transducers. Their bandwidth is large in comparison to conventional piezoceramic transducers. Foil transducers offer new applications for ultrasonic sensors in connection with digital signal processing algorithms. (Author abstract) 3 Refs.

**1991 Title: OPTICAL FIBER FLOWMETER WITH TEMPERATURE CORRECTION.**

**Author:** Herzog, J. P.; Roth, P.; Meyrueis, P.

**Source:** Sensors and Actuators, A: Physical v 25 n 1-3 Oct-Jan 1990-1991 p 219-223

**Abstract:** We present the principle of an optical fiber differential pressure sensor and demonstrate its use as a flowmeter employing an effective pressure method. A new technique is presented to calibrate the differential pressure sensor. We discuss the results with particular emphasis on the way we achieve a satisfactory correction of temperature effects. (Author abstract)

**1991 Title: GENERAL PROBLEMS OF AE SENSORS.**

**Author:** Higo, Yakichi; Inaba, Hidehiro

**Source:** ASTM Special Technical Publication n 1077. Publ by ASTM, Philadelphia, PA, USA p 7-24

**Abstract:** The general problems of AE sensors are overviewed. The effects of mounting conditions of sensors on the sensitivity are discussed. Then the



sensitivity measurement methods are compared. The results of a sensor's sensitivity, obtained by NBS and by the Hatano method show that there is very little difference between them. The convenient calibration method for sensor sensitivities, especially the 'acoustic pressure method' and the 'pencil lead fracture method' are discussed. The characteristics of lead, specially standard pencil lead from JAEWG which produce very stable reproducible AE signals, was demonstrated. The characteristics of the lead is quite similar to the lead produced in 1975. Then sensor sensitivities were obtained by the standard lead and are compared with the results of the reciprocal method. (Author abstract) 14 Refs.

**1991 Title: PREDICTION OF CONTACT PARAMETERS USING ULTRASONIC METHOD.**

**Author:** Krolikowski, J.; Szczepek, J.

**Source:** Wear v 148 n 1 Aug 1 p 181-195

**Abstract:** An attempt to apply ultrasonic methods to evaluate the real contact area and the contact stiffness is reported. The ultrasonic method of the study of contact presented is based on the measurements of the coefficient of transmission of the longitudinal ultrasonic waves normally incident at the contact interface. The tested contact was built from two nominally flat ground steel surfaces loaded up to a contact pressure 400 MPa. On the basis of the experimental results and the acoustic model of contact, the fraction of real contact area and the contact stiffness vs. contact pressure were found. To verify the ultrasonic results, these parameters were calculated for the tested contact using the theoretical models of contact of rough surfaces: i.e. the Greenwood-Williamson model, the Whitehouse-Archard-Onions model and the Bush- Gibson-Thomas model. The experimental results appeared to exceed the theoretical ones both for the fraction of the real contact area (10%-100%) and for contact stiffness (40%-100%). (Author abstract) 39 Refs.

**1991 Title: FABRICATION AND CHARACTERIZATION OF SILICON MICROMACHINED THRESHOLD ACCELEROMETERS.**

**Author:** Loke, Y.; McKinnon, G. H.; Brett, M. J.

**Source:** Sensors and Actuators, A: Physical v 29 n 3 Dec p 235-240

**Abstract:** This paper describes the development of a threshold accelerometer for sensing very high acceleration levels. The device, which is fabricated by silicon micromachining techniques, comprises an array of eight normally open switches, each having a different acceleration threshold. Each switch is a miniature silicon dioxide cantilever beam, only 2.2  $\mu\text{m}$  in thickness, with metallization running along its length and fabricated on the surface of a silicon wafer. Under an applied acceleration, the cantilever beam deflects across a 2.5  $\mu\text{m}$  gap and makes contact with another electrode, thus closing a switch. Electrostatic and static centrifuge testing have been performed on the devices. Closing the switches (beams 120 to 400  $\mu\text{m}$  long and 80  $\mu\text{m}$  wide) electrostatically with voltages in the 10 to 70 V region provides a convenient way to pre-test the beams for closure. Under static centrifuge

testing, a maximum of 20 000 g was measured with a cantilever beam 180  $\mu$ m long and 80  $\mu$ m wide. (Author abstract) 15 Refs.

- 1991 Title:** LUBRICANT FILM THICKNESS MEASUREMENTS IN A DIESEL ENGINE PISTON RING ZONE.

**Author:** Lux, Jeffrey P.; Hoult, David P.

**Source:** Lubrication Engineering v 47 n 5 May p 353-364

**Abstract:** Oil film behavior at the piston ring-cylinder wall interface was studied in a modified version of the four stroke cycle diesel engine. The technique used to measure film thickness was one of laser fluorescence through a quartz window inserted flush into the cylinder liner. Previously, such experiments have been conducted in motored rigs that did not permit fired engine operation. This study extended the technique to a fired engine and discusses a survey of the results. Film thickness data is compared for each stroke to discern lubrication trends for different parts of the engine operating cycle. The data is used as a means to infer local oil transport results in the oil control region of the piston. One of the primary difficulties with measuring oil film thickness with a laser fluorescent technique is the calibration of the system. The authors used tool marks on the skirt of a production piston to calibrate the signal for these experiments. These results were compared to the results of a bench calibration. Although the difference between the two techniques is appreciable, the calibration from the tool marks is within the total calibration range defined in the bench calibration. The dominant quantity of oil resides in the oil control region of the piston. The oil control rails are fully flooded for all conditions. Within the oil control region, the beveled area on the piston beneath the oil control ring has the majority of oil. Film thicknesses in the region of the piston bevel were on the order of 200  $\mu$ m. Upstrokes were typically found to have thicker films than downstrokes, and gas exchange strokes typically had thicker films than either compression or expansion strokes. Oil transport results indicated that local oil flows are much larger than oil consumption. The local flow reverses directions on power revolutions at 2000 RPM. No effects of load on local flows were apparent. (Author abstract) 11 Refs.

- 1991 Title:** NEW-TYPE CALORIMETRIC GAS SENSOR USING TEMPERATURE CHARACTERISTICS OF PIEZOELECTRIC QUARTZ CRYSTAL FITTED WITH NOBLE METAL CATALYST FILM.

**Author:** Miura, Norio; Minamoto, Hirohiko; Sakai, Go; Yamazoe, Noboru

**Source:** Sensors and Actuators, B: Chemical v B5 n 1-4 Aug-Dec p 211-217

**Abstract:** A new type of piezoelectric crystal sensor coated with a sputtered noble metal (Pt, Pd, Ir, or Pt-Ir) film is proposed for the detection of inflammable gases, such as  $H_2$ , CO and isobutane diluted with air, in the temperature range 100-400 degree C. Its sensing principle utilizes an increase in resonance frequency of the quartz crystal with the increase in temperature due to the oxidation of an inflammable gas on the coated catalyst film. Experiments show that the sensitivity increases linearly with  $H_2$

concentration up to 0.4 vol.%, with a 90% response time of about 20s to 0.3 vol.% H<sub>2</sub> at 200 degree C. The sensitivity is dependent on the operation temperature due to the temperature-dependent resonance frequency of the crystal. Among the various coating films tested, sputtered Pt-Ir film gives the best sensor, with high sensitivity to inflammable gases and high resistance to interference by coexisting water vapour. (Author abstract) 12 Refs.

**1991 Title: PIEZORESISTIVE PRESSURE SENSORS BASED ON POLYCRYSTALLINE SILICON.**

**Author:** Mosser, V.; Suski, J.; Goss, J.; Obermeier, E.

**Source:** Sensors and Actuators, A: Physical v 28 n 2 Jul p 113-132

**Abstract:** Polycrystalline Si (poly-Si) has found various applications in microelectronics and micromechanical devices such as pressure sensors, accelerometers and actuators. Poly-Si films deposited on an oxidized Si substrate can combine the excellent mechanical properties of Si with the efficient electrical insulation of poly-Si piezoresistors, so that improved stability and high-temperature operation can be obtained. Different poly-Si fabrication techniques are reviewed with emphasis on their applications to pressure sensors. The theoretical interpretation and models of the piezoresistivity in poly-Si and experimental results are presented. The calculation of the longitudinal and transverse gauge factors and their correlation with the crystallographic structure of the poly-Si film are discussed. The possibility of sensor performance optimization including mechanical, temperature and piezoresistive properties of a device is demonstrated. Two examples of commercially manufactured poly-Si sensors and an example of a new poly-Si technology are also presented. (Author abstract) 62 Refs.

**1991 Title: THREE-DIMENSIONAL POSITION DETERMINATION FROM MOTION.**

**Author:** Nashman, Marilyn; Chaconas, Karen

**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 1383. Publ by Int Soc for Optical Engineering, Bellingham, WA, USA p 166-175

**Abstract:** The analysis of sequences of images over time provides a means of extracting meaningful information which is used to compute and track the three-dimensional position of a moving object. This paper describes an application in which sensory feedback based on time-varying camera images is used to provide position information to a manipulator control system. The system operates in a real-time environment and provides updated information at a rate which permits intelligent trajectory planning by the control system. (Author abstract)

**1991 Title: SURFACE MICROMACHINED ACCELEROMETER. A TECHNOLOGY UPDATE.**

**Author:** Payne, Richard S.; Dinsmore, Kristin A.

**Source:** Sensors & Actuators 1991 Proceedings - Society of Automotive Engineers n P-242. Publ by SAE, Warrendale, PA, USA p 127-135

**Abstract:** The measurement of acceleration has been accomplished using several technologies in high-reliability applications such as detonation, guidance control, and shock and vibration measurement. Electromechanical, piezoelectric, piezoresistive and capacitive acceleration sensors are available and in use today. The application of these technologies in the automobile industry has been slow, largely due to their high cost. Today, numerous companies are working hard to develop a cost-effective, reliable and complete automotive accelerometer for use in airbag deployment, seat belt retraction, door lock control, adaptive suspensions, anti-lock brakes and traction control systems. This paper will compare and contrast the various technologies now being applied to the development of a small and cost-effective electronic accelerometer device, and report on the progress in developing a complete, monolithic, signal-conditioned accelerometer which will optimally address automotive requirements. (Author abstract)

**1991 Title:** PIEZOCERAMICS AND SENSOR APPLICATIONS.

**Author:** Petrucci, Russell

**Source:** Sensors (Peterborough, NH) v 8 n 9 Sep 7p

**Abstract:** Piezoelectric ceramics, termed piezoceramics are used in a variety of sensor applications. The discussion of piezoelectric theory, piezoceramic properties, and four specific piezoceramic sensor applications in switches, acoustic emission, medical diagnostics, and flow monitoring gives a fuller understanding of the use of piezoceramics and the unique flexibility of the materials in sensing applications.

**1991 Title:** SOS STRAIN GAUGE SENSORS FOR FORCE AND PRESSURE TRANSDUCERS.

**Author:** Stuchebnikov, V. M.

**Source:** Sensors and Actuators, A: Physical v 28 n 3 Aug p 207-213

**Abstract:** A set of semiconductor force and pressure sensors developed on the basis of heteroepitaxial layers of silicon on sapphire (SOS) is briefly described. Physico-technological optimization of the SOS sensing elements makes it possible to create transducers for pressure measurement of cryogenic (down to 1 K), normal- and high-temperature (up to 350 degree C) media without compensating elements and with a very small error due to temperature sensitivity, as well as radiation-resistant transducers. (Author abstract) 31 Refs.

**1991 Title:** SMALL SINGLE-SENSOR FOR TEMPERATURE, FLOW, AND PRESSURE MEASUREMENT.

**Author:** Sun, Mei H.; Kamal, Arvind

**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 1420. Publ by Int Soc for Optical Engineering, Bellingham, WA, USA p 44-52

**Abstract:** A small fiber-optic sensor capable of measuring three parameters (temperature, pressure, and flow) is described. This sensor combines three distinct technologies and yet uses a single optical fiber. The temperature measurement is based on the photoluminescent decay time technology used commercially by Luxtron. Pressure is sensed by measuring the intensity of the return signal from a reflector or photoluminescent layer on the outer surface of a compressible dome-shaped optical element formed on the tip of the fiber. The local flow rate measurement is made by an optical heat balance technique similar to that used in more conventional hot wire (or hot film) anemometry. Studies conducted recently indicate that a submillimeter diameter sensor of this type can be built and should be suitable for in-vivo measurements in various applications such as during radio frequency (RF) or microwave heated angioplasty and in a continuous cardiac output monitoring. (Author abstract) 5 Refs.

**1991 Title:** IN-SITU ELECTRO-CHARGING FOR FRICTION REDUCTION AND WEAR RESISTANT FILM FORMATION.

**Author:** Tung, S.C.; Wang, S.S.

**Source:** Tribology Transactions v 34 4 p 479-488.

**Abstract:** A technique has been developed to form friction-reducing and antiwear films in-situ by means of an electric field applied between rubbing metal surfaces. Using this in-situ charging technique, the effectiveness of zinc organodithiophosphate (ZDP) additives as antiwear and friction reducing agents can be enhanced by electrochemical reactions which form surface coatings. The coatings formed on sliding surfaces compared with uncharged surfaces reduce friction by up to 35 percent. In addition, during the sliding process, the films formed on the surfaces are replenished and protect the rubbing surfaces from wear. A steel plate subjected to rubbing and in-situ charging for four hours had a smooth surface and a yellowish reaction film; the one without charging was rougher and no yellowish reaction film was formed. The improved tribological characteristics are attributed to an increase in the electrochemical reactivity of the ZDP-mineral oil blends and the formation of phosphate or sulfate films on the metal surfaces.

**1991 Title:** USE OF AUTOMATED IMAGE ANALYSIS FOR THE STUDY OF WEAR PARTICLES IN OIL- LUBRICATED TRIBOLOGICAL SYSTEMS.

**Author:** Uedelhoven, W.; Franzl, M.; Guttenberger, J.

**Source:** Wear v 142 n 1 Feb 1 p 107-113

**Abstract:** Automated image analysis is used to evaluate particle dimensions in ferrographic precipitated wear debris. The wear particles are made accessible to microscopic investigation by employing a particular sample preparation technique. Preliminary results from investigations of jet turbine and helicopter transmission lubricating oils show a significant change in particle size and shape as a function of advancing failure. The data are compared with results of laboratory wear test devices (Ryder test) as well as other condition monitoring methods (SOAP). (Author abstract) 8 Refs.

- 1991 Title:** PIEZOELECTRICALLY DRIVEN SILICON BEAM FORCE SENSOR.  
**Author:** Van Mullem, C. J.; Blom, F. R.; Fluitman, J. H. J.; Elwenspoek, M.  
**Source:** Sensors and Actuators, A: Physical v 26 n 1-3 Mar p 379-383  
**Abstract:** A resonant silicon beam force sensor with piezoelectric excitation and detection is being developed. The realization is based on IC and thin-film technology with ZnO as the piezoelectrical layer. The theory, realization and measurements of a bent-frame sensors are described. A frequency shift of about 3.3 times the unloaded resonance frequency  $f//0$  ( $f//0$  congruent 6 kHz) is measured with an external load force up to 0.4 N. The absolute sensitivity of the force sensor is 64 kHz/N and the full-scale sensitivity is 29 kHz/N. Using a simple model for the load-force transduction from external to sensor force, the measurements are in good agreement with the theory. (Author abstract) 7 Refs.
- 1991 Title:** FIBER-OPTIC DIAPHRAGM PRESSURE SENSOR WITH AUTOMATIC INTENSITY COMPENSATION.  
**Author:** Yuan, Libo; Qiu, Anping  
**Source:** Sensors and Actuators, A: Physical v 28 n 1 Jun p 29-33  
**Abstract:** A new type of fiber-optic sensor that determines pressure from a diaphragm displacement is discussed. This sensing technique automatically compensates for variation in the source intensity, for losses in the input fibers and for variations in the reflectivity of the diaphragm surface. Experimental results are presented for a low-pressure transducer suitable for measuring liquid levels. (Author abstract) 12 Refs.
- 1991 Title:** NEW MEASUREMENT METHOD OF OIL FILM THICKNESS IN THE EHL CONDITION. THE R-C OSCILLATION TECHNIQUE.  
**Author:** Zhang, Peng-shun; Li, Shu-guang; Zhai, Wen-jie  
**Source:** Wear v 148 n 1 Aug 1 p 39-46  
**Abstract:** In this paper we propose a new measurement method of oil film thickness in the elastohydrodynamic lubrication (EHL) state, which is called the resistance-capacitance (R-C) oscillation technique. By experiment, it is proved that not only can the technique be used in the full EHL state, but also it can measure the non-contact time ratio in mixed lubrication. It can convey clearly the EHL state quantitatively, and it proved to be a more effective measurement method in practice and a better technique than those used before. (Author abstract) 5 Refs.
- 1991 Title:** SIMPLE CAPACITIVE DISPLACEMENT SENSOR.  
**Author:** Zhu, F.; Spronck, J. W.; Heerens, W. C.  
**Source:** Sensors and Actuators, A: Physical v 26 n 1-3 Mar p 265-269  
**Abstract:** This paper presents a simple capacitive displacement sensor based on the application of spatial sampling and Doppler measurement techniques. The theoretical performance of the sensor has been predicted and simulated on a PC, and confirmed experimentally. The prototype sensor shows a

resolution and repeatability of 1  $\mu$  m. A linear measurement range up to a few meters can be achieved. (Author abstract)

- 1991 Title:** ALGAAS SEMICONDUCTOR PRESSURE SENSORS.  
**Author:** Zilionis, S.; Stankevic, V.  
**Source:** Sensors and Actuators, A: Physical v 26 n 1-3 Mar p 295-299  
**Abstract:** The use of graded-composition epitaxial films of mixed compound semiconductor Al//xGa//1// minus //xAs as high-pressure sensors has been studied. It is shown that sensors made of Al//xGa//1// minus //xAs films have a high sensitivity to uniform pressure (5-10%/100 MPa), a nearly linear dependence of resistance on pressure (non-linearity in the range 0-1 GPa is less than 2%) and a small temperature coefficient of sensitivity (about 0.02%/K). At the same time a small temperature coefficient of resistance (less than 0.02%/K) at atmospheric pressure can be obtained. The AlGaAs pressure sensors are suitable for the measurement of pressure up to 1 GPa in the temperature range 120-400 K. (Author abstract)
- 1990 Title:** CEPSTRUM ANALYSIS PREDICTS GEARBOX FAILURE.  
**Author:** Aatola, S.; Leskinen, R.  
**Source:** Noise Control Engineering Journal v 34 n 2 Mar-Apr p 53-59  
**Abstract:** A one-step gearbox was run under controlled laboratory conditions until failure occurred during continuous operation with an overload of about 50 percent. The gearbox ran for a total of 497 hours, until three teeth of the input gear broke at the base as a result of fatigue. Gearbox vibrations and temperatures were measured during operation. The following analyses of vibration signals were used for condition monitoring: spectrum analysis; cepstrum analysis; acoustic emission; and statistical analysis. The imminent failure could be predicted only marginally on the basis of spectrum analysis, but more accurately on the basis of cepstrum analysis. Under normal load conditions, a failure of this type might be predicted by cepstrum analysis several days in advance. (Author abstract) 5 Refs.
- 1990 Title:** CRYOGENIC PRESSURE SENSOR CALIBRATION FACILITY.  
**Author:** Boyd, C.; Juanarena, D.; Rao, M. G.  
**Source:** Advances in Cryogenic Engineering v 35 pt B. Publ by Plenum Publ Corp, New York, NY, USA p 1573-1581  
**Abstract:** Cold silicon piezoresistive strain gauge pressure sensors have several advantages over the conventional pressure measuring devices/systems used in cryogenics. A cryogenic pressure sensor calibration facility has been set up at Pressure Systems, Inc. for calibrating cryogenic pressure sensors in the temperature range 1.5-400 K. This paper presents a brief review of this calibration facility together with the low temperature characteristics of the cryogenic piezoresistive pressure sensors. The pressure sensors calibrated so far include 202 k Pa absolute (30 psia), 202 k Pa differential (30 psid) and 1013 k Pa absolute (150 psia) range devices. These calibrations are linear and are repeatable to within plus or minus 0.1% and

plus or minus 0.5% full scale outputs for 202 k Pa and 1013 k Pa range pressure sensors respectively. (Author abstract) 4 Refs.

- 1990 Title:** ON-LINE ULTRASONIC MONITORING OF BEARING WEAR.  
**Author:** Chann, Jeffrey C.  
**Source:** Turbomachinery International v 31 n 7 Nov-Dec p 12-18  
**Abstract:** A bearing wear monitoring system has been developed to eliminate the interpretation of indirect symptoms and the need for bearing disassembly. The level of accuracy provides a diagnostic ability far more sensitive to wear than indirect methods such as vibration monitoring. In addition, the system provides data on the location and the extent of the problem. Finally, the ultrasonic technique reduces inspection costs, and eliminates the risk of improper reassembly that may follow inspections. (Edited author abstract)
- 1990 Title:** ABSOLUTE PRESSURE SENSORS BY AIR-TIGHT ELECTRICAL FEEDTHROUGH STRUCTURE.  
**Author:** Esashi, Masayoshi; Matsumoto, Yoshinori; Shoji, Shuichi  
**Source:** Sensors and Actuators, A: Physical v 23 n 1-3 Apr p 1048-1052  
**Abstract:** A new electrical feedthrough structure for silicon absolute pressure sensors has been developed, and has been applied to an integrated capacitive pressure sensor, a piezoresistive pressure sensor and a piezoresistive force sensor array for tactile imaging. The feedthrough structure is constructed from Pyrex glass, which has narrow through-holes engraved by electrochemical discharge drilling, and silicon, which has the diffused electrical feedthrough from the reference cavity. The reference cavity is hermetically sealed by glass - silicon anodic bonding. This structure is useful for the fabrication of absolute pressure sensors, acceleration sensors and so on. (Edited author abstract) 4 Refs.
- 1990 Title:** IN SITU PISTON RING WEAR MEASUREMENTS IN A MEDIUM-SPEED DIESEL ENGINE.  
**Author:** Fritz, S. G.; Cataldi, G. R.  
**Source:** Lubrication Engineering v 46 n 6 Jun p 365-370  
**Abstract:** In-situ piston ring wear was determined in a Single Cylinder Medium-Speed diesel engine using thin film surface layer activation (SLA). Top compression ring wear was quantified over a 500-hour test period for three different types of cylinder liner surface finishing techniques. Lubricating oil consumption rates and motoring friction horsepower requirements were also determined. The SLA technique is discussed along with the design and operation of the Single Cylinder Research Engine (SCRE). The SCRE facility is centered around a Bombardier model 251-plus 11.0 L engine which is representative of medium-speed four-stroke multicylinder railroad, marine and stationary powerplant engines. 11 Refs.



**1990 Title:** IN SITU FRICTION AND WEAR MEASUREMENTS IN INTEGRATED POLYSILICON MECHANISMS.

**Author:** Gabriel, K. J.; Behi, F.; Mahadevan, R.; Mehregany, M.

**Source:** Sensors and Actuators, A: Physical v 21 n 1-3 2 Pt2 p 184-188

**Abstract:** We describe a series of experiments, in situ measurements and theoretical models designed to provide estimates of the coefficients of friction and the nature of wear in integrated polysilicon micromechanisms. A laser-based measurement system was used to monitor the motion of the rotating micromechanisms and steady-state speeds of up to 10 000 rps (600 000 rpm) were recorded. We estimated dynamic coefficients of friction for polysilicon on silicon ranging in value from 0.25 to 0.35. The results were reproducible on numerous components, across structures of identical and different geometries, produced on different wafers from the same fabrication lot. Life-cycles for some of these structures were determined under various operating conditions, with typical components surviving for almost one million cycles. (Edited author abstract) 10 Refs.

**1990 Title:** DEVELOPMENT OF AE SOURCE INVERSION SYSTEM AND AN APPLICATION TO THE MONITORING OF HYDROGEN ASSISTED CRACKING OF LOW ALLOY STEEL.

**Author:** Hayashi, Yasuhisa; Takemoto, Mikio

**Source:** Boshoku Gijutsu/Corrosion Engineering v 39 n 7 p 347-354

**Abstract:** In order to elucidate the microkinetics of hydrogen assisted cracking of low alloy steel, a newly developed acoustic emission (AE) source inversion system was used. The paper discusses some problems in applying this system to monitor the kinetics of microcrack. The AE monitoring system is composed of a displacement type transducer, preamplifier, high speed A/D converter and personal computer. The transfer function measures the surface displacement without giving wave distortion up to 1.5 MHz. Computer software for AE source inversion made it possible to calculate the second Green's function (transfer function) simulate the surface displacement and calculate the source waves from detected waves. The crack size was calculated from released energy with the assistance of fracture mechanics, and fairly well agrees with the hydrogen-induced intergranular fracture area. (Edited author abstract) 12 Refs. In Japanese.

**1990 Title:** PLANAR FIBER OPTIC ACOUSTIC SENSORS.

**Author:** Lagakos, N.; Hickman, T. R.; Ehrenfeuchter, P.; Bucaro, J. A.; Dandridge, A.

**Source:** Technical Digest Series Opt Fiber Commun Conf OFC 90. Publ by Optical Soc of America, Washington, DC, USA (IEEE cat n 90CH2821-7) p 46

**Abstract:** A transduction mechanism for acoustic detection that offers both shape flexibility and immunity to electromagnetic interference is phase modulation in single-mode fibers. Here, a flexible planar fiber-optic acoustic sensor is reported. The fiber is wrapped in a spiral form that is embedded in a polymer (polyurethane) layer forming a planar sensor. The basic fiber was a

high numerical aperture (0.17) single-mode fiber with an 80-  $\mu$ m outside diameter and 100-  $\mu$ m buffer jacket of silicon. The 32-m-long sensing fiber had an additional 350-  $\mu$ m coating of polyester, making its total diameter 1 mm. This fiber spiral was then embedded in the corner of a polyurethane layer, the overall size of which was 30 cm multiplied by 30 cm multiplied by 6 mm. Great care and controlled fabrication conditions were maintained to avoid encapsulation of even the smallest air inclusions within the integrated structure. The acoustic sensitivity of the planar fiber-optic sensor was studied. The acoustic response of the sensor in water in the frequency range of 0.25-2.5 kHz is frequency independent. The planar fiber acoustic sensor was compared with a polyvinylidene fluoride (PVF//2) sensor of similar geometry. In an acceleration controlled environment the fiber sensor acoustic response outperformed that of the PVF//2. 2 Refs.

**1990 Title:** APPLICATION OF VIBRATING BEAM TECHNOLOGY TO DIGITAL ACCELERATION MEASUREMENT.

**Author:** Meldrum, M. A.

**Source:** Sensors and Actuators, A: Physical v 21 n 1-3 2 Pt2 p 377-380

**Abstract:** Vibrating beam technology is currently being used for many types of static and dynamic transducer applications for the measurement of temperature, pressure, load and acceleration. This paper describes the application of a piezoelectric quartz vibrating beam in a digital accelerometer. The dynamic environment, in which this instrument must operate, poses some significant design challenges that are not encountered in transducer design for static applications. This paper will describe the design, performance and test results of an accelerometer used for vehicle control and navigation applications. (Author abstract) 0 Refs.

**1990 Title:** PIEZOELECTRIC RESONATOR AS A CHEMICAL AND BIOCHEMICAL SENSING DEVICE.

**Author:** Muramatsu, H.; Suda, M.; Ataka, T.; Seki, A.; Tamiya, E.; Karube, I.

**Source:** Sensors and Actuators, A: Physical v 21 n 1-3 2 Pt2 p 362-368

**Abstract:** This paper introduces the application of the piezoelectric resonator to a chemical and biochemical sensing. The device was used for viscosity and surface mass change measurement. Viscosity measurement was applied for gelation detection; where endotoxin and fibrinogen were determined, and also thermal analysis, where phase transition of liquid crystal was detected. Surface mass change was applied to electrochemical measurement, where Prussian blue film formation and reaction of the film were monitored, and odorant detection, in which n-amyl acetate, citral, beta -ionone and menthone were detected. (Author abstract) 21 Refs.

**1990 Title:** ON-LINE TRIBOLOGY MEASUREMENTS ON LUBRICATED RIGID DISKS.

**Author:** Nunnelley, L. L.; Burleson, M. A.; Fuller, G. G.

**Source:** IEEE Transactions on Magnetics v 26 n 5 Sep p 2679-2681

**Abstract:** A high-speed ellipsometer has been devised for online wear measurements of recording media. The instrument can either determine spatially resolved film-thickness profiles across a wear track or make high-speed measurements of the angular dependence of wear damage as the test specimen rotates. In its present configuration, data-acquisition rates of 300 Hz are possible. Experiments on thin film demonstrate the ability of the technique to monitor thin-film profiles and to reveal the progression of wear from the ablation of the lubricant layer to the removal of the magnetic film. 4 Refs.

- 1990 Title:** DEVELOPMENT OF AN ORIENTATION SENSOR.  
**Author:** Partaatmadja, O.; Benhabib, B.; Kaizerman, E.; Goldenberg, A. A.  
**Source:** Proc 1990 ASME Des Tech Conf 2 Conf Flexible Assem Syst American Society of Mechanical Engineers, Design Engineering Division (Publication) DE v 28. Publ by ASME, New York, NY, USA p 161-169  
**Abstract:** The development of a non-contact electro-optical orientation sensor is addressed in this paper. The sensor is based on the intensity measurement of light signals reflected from the surface of an inclined object. The experimental set-up of the sensor used in this research, was designed and manufactured such that two mechanical-design parameters could be investigated. The operation principle of the one-dimensional inclination-angle measurement sensor was verified using the experimental set-up. Experiments undertaken yielded an optimal sensor design which can effectively operate within plus 20 degree to minus 20 degree range independent of its distance to the object. (Author abstract) 10 Refs.
- 1990 Title:** DETECTION OF DEVELOPING BEARING FAILURES BY MEANS OF VIBRATION.  
**Author:** Reif, Z.; Lai, M. S.  
**Source:** American Society of Mechanical Engineers, Design Engineering Division (Publication) DE v 18-1. Publ by American Soc of Mechanical Engineers (ASME), New York, NY, USA p 231-236  
**Abstract:** The use of vibration as a sensing medium for measurements in predictive and preventive maintenance is surveyed. Specific aspects of its applications for detecting the early development of failures in rolling element bearings are discussed and several procedures are evaluated. Some experimental results of a research project, with the objective of determining the basic relationships between developing ball bearing failures and the resulting changes in vibration response, are presented with specific emphasis on the comparison of measuring effectiveness in low and high frequency ranges. It is concluded that for the majority of industrial applications best results are obtained by monitoring vibration acceleration in the frequency band of approximately 6 KHz to 20 KHz. (Author abstract) 12 Refs.
- 1990 Title:** PIEZORESISTIVE LOW-PRESSURE SENSOR WITH HIGH SENSITIVITY AND HIGH ACCURACY.

**Author:** Sandmaier, H.; Kuehl, K.

**Source:** Sensors and Actuators, A: Physical v 21 n 1-3 2 Pt2 p 142-145

**Abstract:** A piezoresistive low-pressure sensor featuring a variety of advantages because of its novel design is introduced. The main objective of this development was to realize a sensor with high sensitivity, high overload capacity, and low linearity error. This publication describes the theory for the design of the piezoresistive low-pressure sensor. In comparison to familiar sensor concepts, the sensor developed for the pressure range of plus or minus 10 kPa exhibits excellent properties (sensitivity equals 35 mV/V full-scale output and linearity error equals 0.05%). The sensor characteristics determined theoretically were confirmed by measurements on realized pressure sensors. (Author abstract) 6 Refs.

**1990 Title:** ON-LINE TOOL WEAR SENSING AND COMPENSATION DURING TURNING OPERATION.

**Author:** Sanjanwala, A.; Choudhury, S. K.; Jain, V. K.

**Source:** Precision Engineering v 12 n 2 Apr p 81-84

**Abstract:** Dimensional inaccuracies are one of the major problems during the turning of a long workpiece. This is explained by the fact that flank wear on the tool causes a tapering effect. This paper describes the design and testing of a pneumatic feedback system that can be mounted on a centre lathe to improve the dimensional stability during turning by on-line tool wear sensing and compensation. The proposed system consists of a pneumatic sensor to sense the tool wear during machining, a pilot-controlled direction control valve to amplify the signal obtained from the pneumatic sensor and an actuating mechanism to move the tool for compensation of dimensional inaccuracies. The proposed system is tested for various cutting conditions. The experimental results show that the use of the proposed feedback system results in improved dimensional accuracy. (Edited author abstract) 10 Refs.

**1990 Title:** USE OF DIGITAL IMAGE PROCESSING TECHNIQUES FOR ANALYSIS OF LUBRICANT OXIDATION PRODUCTS.

**Author:** Schilowitz, A.M.; Espino, R.L.; Don, H.S.

**Source:** Tribology Transactions v 33 2 p 193-200.

**Abstract:** A low cost, personal computer based, image processing system has been developed to automatically analyze and numerically rate deposits on metal surfaces generated in lubricant oxidation stability tests. Such tests are routinely used for evaluating and developing new engine lubricant technology. In many cases it is difficult to effectively and reproducibly evaluate these deposits with manual rating methods. Software has been developed to process images of deposits in two stages. In the first stage the image is segmented to extract the area of deposit. In the second state image analysis techniques are applied to the extracted region and relevant parameter such as mean darkness, area of deposit and texture of deposit are computed. To compute deposit texture second order grey level statistics are used. These methods are applicable to a variety of lubricant and fuel test procedures.

**1990 Title:** DEFORMATION AND STRAIN FIELDS IN PIN SPECIMENS IN SLIDING CONTACT BY LASER SPECKLE AND METALLOGRAPHIC TECHNIQUES.

**Author:** Seif, M.A.; Mohr, P.J.; Moslehy, F.A.; Rice, S.L.

**Source:** Transactions of the ASME v 112 p 506.

**Abstract:** This paper describes the application of laser speckle photography to the measurement of deformations associated with sliding wear. The deformation and the associated strains are those which occur on the "side" of a rectangular-sectioned pin which is in sliding contact against a counterface disc. The side of the pin is exposed to a pulsed ruby laser beam, and a double exposure specklegram is made to record deformations which occur between laser pulses. Strain fields are obtained from displacement data by use of the Lagrangian description, and neglecting out-of-plane displacement gradients. By appropriately sequencing pulses, deformation histories can be obtained, *in situ*. And since the exposed side of the thin pin specimen represents the "cover" layer under which subsurface sections lie, the deformation history observable through the laser speckle method reflects the deformation behavior which is occurring on subsurface planes. By post-test metallography on planes close to this side face, the degree of correspondence between surface and subsurface deformation fields is demonstrated. The paper discusses the materials, apparatus and experimental techniques employed, and presents results obtained with several metallic specimens. Of particular interest is the extent of the plastically deformed subsurface zone, and its development as a function of time.

**1990 Title:** MICROSENSORS FOR HEAT TRANSFER AND FLUID FLOW MEASUREMENTS.

**Author:** Udell, Kent S.; Pisano, Albert P.; Howe, Roger T.; Muller, Richard S.; White, Richard M.

**Source:** Experimental Thermal and Fluid Science v 3 n 1 Jan p 52-59

**Abstract:** Ongoing research on the fabrication, performance, and application of microsensors is described from the viewpoint of their use for heat transfer and fluid flow measurements. Fabrication techniques that provide micromachining capabilities for various microscale elements are discussed. The thermal and fluid microenvironment characteristic of these sensors is addressed in detail. Performance characteristics of prototype pressure sensors, humidity sensors, microviscometers, thermistors, thermocouples, and flowmeters are presented. The operation of several integrated microsensors is discussed. Potential applications are mentioned, both as low-cost substitutes for existing transducers and as specialty devices for high spatial resolution and fast response needs. Finally, the use of these ultrasmall-scale transducers for fundamental research related to microscale heat and mass transfer is explored. (Author abstract) 30 Refs.

**1989 Title:** DETERMINATION OF THE SHEAR STRESSES OF LUBRICANTS IN ELASTOHYDRODYNAMIC CONTACTS.

**Author:** Cann, P.M.; Spikes, H.A.

**Source:** Tribology Transactions 32 3 p 414-422.

**Abstract:** The need for increased efficiency in transmission has focused attention upon the traction characteristics of lubricants in elastohydrodynamic contacts. Until now most studies in this field have employed a disc machine to obtain mean values of traction coefficient across an entire elastohydrodynamic contact. This obscures details of the way the lubricant responds to the varying pressure and temperature across the contact.

This paper describes a method of obtaining local shear stresses of lubricants as they vary across a sliding contact. Infrared radiometry is employed to measure the surface temperature profile of a lubricated steel surface sliding against a static sapphire window. Mean shear stress profiles are obtained from these temperatures using standard heat conduction theory for a finite width, finite length moving heat source. Results are compared with data obtained using conventional traction and a shear stress measurements.

**1989 Title:** ACOUSTIC EMISSION TESTING THE F-111.

**Author:** Carlyle, J. M.

**Source:** NDT International v 22 n 2 Apr p 67-73

**Abstract:** Significant portions of the F-111 aircraft were fabricated of D6AC steel, which is now known to have a fairly small critical crack size. To prove structural flight-worthiness the Air Force built a chamber at McClellan AFB, where all F-111 aircraft are periodically chilled to minus 40 degree C and stressed to plus 7.3 g and minus 3.0 g. Recently the chamber was modernized, and Physical Acoustics Corporation was selected to supply an acoustic emission system to locate any sources of structural failure. The new F-111 Cold Proof Test Station Acoustic Emission Monitoring System has several innovative features, including a color CRT which displays the exact location of AE events in real time on simultaneous overhead and side views of the F-111. The events are colored green, yellow and red according to their severity, as calculated from their amplitude and energy. A monochromatic CRT is used concurrently with the color CRT to display severity information on AE events which only arrive at one sensor. Alarms also audibly alert the operator to crucial events, using two tones to distinguish the degree of severity. (Author abstract) 6 Refs.

**1989 Title:** SAW SENSORS.

**Author:** D'Amico, A.; Verona, E.

**Source:** Sensors and Actuators v 17 1-2 PT1 May 3 p 55-66

**Abstract:** This paper considers recent developments in surface acoustic wave sensors (SAW) and illustrates the operating principle of both physical and chemical SAW based on surface acoustic wave (SAW) propagation velocity variations. The SAW that have appeared in the literature so far are qualitatively reviewed and compared with other existing sensors based on

different working principles. It is concluded that for producing low-cost integrated SAW for future applications, combined piezoelectric-silicon technology must be further developed. (Author abstract) 53 Refs.

**1989 Title: NONCONTACT TEMPERATURE SENSING WITH THIN FILM THERMOPILE DETECTORS.**

**Author:** Hamel, Conrad

**Source:** Sensors (Peterborough, NH) v 6 n 1 Jan p 28-32

**Abstract:** Because of its small size and relatively fast response, the thin film thermopile detector has become the detector of choice for the majority of the instruments measuring temperature in the 0 to 1500 degree C range. The theory of infrared radiation is outlined, along with an optical system based on thermopile detectors. Signed conditioning is discussed.

**1989 Title: ACOUSTIC EMISSION MONITORING OF ROLLING ELEMENT BEARINGS.**

**Author:** Hawman, M. W.; Galinaitis, W. S.

**Source:** Ultrasonics Symposium Proceedings v 2. Publ by IEEE, IEEE Service Center, Piscataway, NJ, USA p 885-889

**Abstract:** The authors describe experimental efforts aimed at establishing the detection threshold for acoustic emission (AE) and vibration monitoring for a typical defect located in a standard ball bearing. An AE point contact transducer (PCT) has been developed; it is a rugged and compact device that can be used for various machinery diagnostic applications. Stress wave emissions in the frequency range above 100 kHz can provide a clear indication of the defect and thus provide an earlier and more reliable indication of bearing degradation. The digital data acquisition and analysis system used with the AE PCT is described, and AE and vibration analysis results are presented. 5 refs.

**1989 Title: IMPLEMENTATION OF FIBER OPTICS IN U.S. NAVAL COMBATANTS.**

**Author:** Johnston, R. A.; Stewart, R. C.

**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 840. Publ by Int Soc for Optical Engineering, Bellingham, WA, USA p 80-93

**Abstract:** This paper describes a program wherein fiber optic technology was introduced into the US Navy's AEGIS Cruisers. Although specific to one ship class, the program achievements are applicable to most naval as well as commercial ships. Developments include a unique cable design, junction boxes, connectors, a splice, emergency repair procedures, a remote motor control system, a torsionmeter system, and a family of sensors and switches. The paper concludes that the past issues that prevented the use of fiber optic technology in naval ships have been addressed and resolved. Fiber optics has successfully been introduced into naval combatants in data transmission, control, and sensing applications. (Edited author abstract) 3 Refs.

- 1989 Title:** DEVELOPMENT OF SENSING SYSTEM OF PIEZOELECTRIC CERAMICS MEASURING CONTACT PRESSURE DISTRIBUTION (ON TECHNIQUES TO INCREASE MEASURING POINTS AND SPEED).  
**Author:** Oda, Juhachi; Moto, Satoru; Inoue, Jirou; Tabota, Jun  
**Source:** Nippon Kikai Gakkai Ronbunshu, A Hen/Transactions of the Japan Society of Mechanical Engineers, Part A v 55 n 513 May p 1230-1235  
**Abstract:** Improvement techniques of the sensing system proposed in the previous paper are described. By the sensing system, optional contact pressure distributions are measured automatically. In the system, piezoelectric ceramics are used and a special electric circuit is designed to measure electric charge in the material. In the electric circuit, the FET with the integral and peak hold circuits is used to increase the measuring points and speed. A sensing system of 20 multiplied by 10 measuring points and a 2-second measuring time is designed. By using this system, the contact pressure distribution for several problems are measured. The obtained total force and the pressure distributions are compared with the corresponding acting forces and the theoretical values. (Author abstract) 7 Refs. In Japanese.
- 1989 Title:** FIBRES ARE READY MADE SENSORS.  
**Author:** Parry, Simon  
**Source:** New Electronics v 22 n 5 Jun p 47  
**Abstract:** The optical flux within a fibre is affected by external influences. There is an electro optic effect, a magneto optic effect and heat will alter the spectrum of the reflected energy. A reflectometer will detect bends in the optical fibre. If the fibre's core is exposed on the bend it can be used for sensing purposes, because the evanescent field will be affected so altering the transmission properties of the fibre.
- 1989 Title:** FIBER OPTIC TORQUEMETER DESIGN AND DEVELOPMENT.  
**Author:** Rudd, Robert E.; Kline, Bruce R.; Hoff, Frederick G.; Spillman, W. B. Jr.  
**Source:** ISA Transactions v 28 n 2 p 19-23  
**Abstract:** An optical torque measurement system has been developed that provides an accurate measurement of angular deflection over a known length of a torsionally loaded rotating shaft. Main advantages of this configuration, as compared to a conventional electromechanical system are EMI immunity, reference sleeve elimination, and dc operation. Independent optical measurements of shaft speed are compared in phase. Shaft torque can then be computed from knowledge of phase difference and shaft spring constant in subsequent signal processing. System accuracy of 0.005 prime was demonstrated using a prototype device that had an operating range of plus or minus 15 prime of relative shaft twist. (Author abstract) 2 Refs.
- 1989 Title:** TEMPERATURE SENSORS: NEW TECHNOLOGIES ON THEIR WAY TO INDUSTRIAL APPLICATION.



**Author:** Schaefer, W.

**Source:** Sensors and Actuators v 17 1-2 PT1 May 3 p 27-37

**Abstract:** Recently fibre-optic temperature sensors and quartz temperature sensors have become available in forms suitable for industrial applications. The basic technology of these sensors will be reviewed and their advantages and disadvantages will be discussed in comparison to features of Pt resistance elements and with regard to general requirements. (Author abstract) 21 Refs.

**1989 Title:** ACOUSTIC EMISSION TRUE RMS SIGNALS USED TO INDICATE WEAR OF A HIGH SPEED CERAMIC INSERT.

**Author:** Yang, Chang-Fei; Houghton, J. Richard

**Source:** Journal of Mechanical Working Technology v 20 Sep p 79-91

**Abstract:** Tool wear measurements are a significant factor in the operation of an automation machine tool installation. This paper reports four methods for detection of tool wear: cutting force, chip direction, temperature rise and acoustic emission signal. The simple combined measurement method will be used to indicate ceramic tool wear or breakage. Ceramic inserts on a lathe single point cutting were used in the tests at high cutting speed. The true root-mean-square, RMS, of the acoustic emission signal measured at the base of the insert is shown to be the most sensitive to tool wear. (Author abstract) 15 Refs.

**1989 Title:** USING FIBEROPTICS FOR PRACTICAL SENSING.

**Author:** Wohlstein, Scott D.

**Source:** Lasers & Optronics v 8 n 7 Jul p 73-76

**Abstract:** Recent reductions in production and material costs have made the acquisition of low-cost fiberoptics easier, allowing for more experimentation in the area of sensing. Older techniques - including the use of phosphor-tipped or reaction-type fibers - trade on the inherent fiber optic advantage of remote location. But these types of sensors cannot be used where interaction by light emission or chemical method is unacceptable. More innocuous methods have had to be developed. Continuing research and sharply declining prices have led to new levels of fiber-sensor engineering; in particular, the use of low-cost, low-grade optical fibers has proven very successful. The author discusses basic fiber transmission, temperature sensing, pressure sensing and system theory with a diode laser coupled to a splitter via a multimode fiber pigtail. 6 Refs.

**1988 Title:** ANTIFRICTION BEARING FAULT DETECTION USING ENVELOPE DETECTION.

**Author:** Burgess, Peter F. J.

**Source:** Transactions of the Institution of Professional Engineers New Zealand, Electrical/Mechanical/Chemical Engineering Section v 15 n 2 Jul p 77-82

**Abstract:** A successful method of detecting bearing faults is described. The transducer is a standard 0-25 kHz industrial accelerometer whose output is

processed by a FFT analyser which gives a digital frequency spectrum of the signal. The method of signal conditioning and the failure detection of two bearing faults is described. The method can detect very minor bearing defects and is a powerful tool for bearing condition monitoring. (Author abstract) 6 Refs.

**1988 Title:** REAL TIME SIMULTANEOUS IN-LINE WEAR AND LUBRICANT CONDITION MONITORING.

**Author:** Centers, P. W.; Price, F. D.

**Source:** Wear v 123 n 3 May p 303-312

**Abstract:** An in-line complete oil breakdown rate analyzer (COBRA) and quantitative debris monitor (QDM) were installed in the oil system of an aircraft turbine engine lubricant simulator. The in-line COBRA readings correlated well with those of a standard laboratory model COBRA and total acid number of the deteriorating lubricant. Increases in QD particle counts corresponded with increases in trace iron content, which reflected abnormal wear occurring in the simulator. Analytical and direct reading ferrographic data confirmed the rapid increase and eventual modest decrease in wear debris concentration. After test completion it was determined that a mainshaft bearing had experienced abnormal wear. Thus, for the first time, successful capability for real-time simultaneous in-line wear and lubricant condition monitoring was demonstrated. (Author abstract) 5 refs.

**1988 Title:** STUDY OF WEAR AND GALLING IN AIRCRAFT FUEL PUMP DRIVE SHAFTS AND GEARS USING THE SURFACE LAYER ACTIVATION TECHNIQUE.

**Author:** Gallmann, A.; Natter, B.; Molinari, M. A.

**Source:** Nuclear Instruments & Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms v B34 n 4 Oct p 479-482

**Abstract:** The surface layer activation technique (SLA) has been applied to study galling and wear in moving parts of Boeing 747 engines. Radioactive  $^{56}\text{Co}$  was formed by the reaction  $^{56}\text{Fe}(p, n)^{56}\text{Co}$  in fuel pump drive shafts and gears, and their residual activities in these activated parts were measured in situ during routine inspections over more than one year. The study of the wear was done on shafts made of a new alloy and on gears having a new tooth geometry. Wear determined by SLA was corroborated by a profile measurement made when one of the pumps was disassembled. The study of the galling (with release of metallic fragments) of a drive shaft consisted in checking the condition of the critical zone of the splines with the SLA technique. The main originality of the present work is that for the first time such measurements were performed on engines in revenue service. (Author abstract) 6 refs.

**1988 Title:** DIAGNOSTICS OF BEARINGS BY STATISTICAL PARAMETERS OF THEIR HIGH FREQUENCY VIBRATIONS.

**Author:** Gudonavicius, R.; Ziogas, V.; Kajackas, A.; Rondonanskas, M.

**Source:** Vibration Engineering (English Translation of Vibrotekhnika) v 2 n 1 p 45-50

**Abstract:** High-frequency vibrations caused by rolling friction bearings present abundant information on their technical conditions. As an example, we shall present the relation of the level of high-frequency vibrations to the technical condition of bearings. This relation shows a high sensitivity of the given parameter to the technical condition of bearings. Therefore, we study high-frequency vibrations caused by rolling friction bearings. The purpose of the work presented here is to prove that statistical characteristics of high-frequency vibrations reflect the condition of bearings. 4 refs.

**1988 Title:** TEMPERATURE MEASUREMENT IN ELASTOHYDRODYNAMIC LUBRICATION CONTACTS USING AN INFRARED TECHNIQUE.

**Author:** Hou, Keping; Wen, Shizhu

**Source:** Tribology International v 21 n 5 Oct p 287-289

**Abstract:** An infrared technique for temperature measurement of rolling and sliding elastohydrodynamic lubrication contacts is presented. A new method of radiation analysis is described, whereby the emissivity of a steel ball is considered a function of temperature. Results of measurement of the temperature of the ball in different rolling and sliding ratios under various loads are presented. (Author abstract) 11 Refs.

**1988 Title:** FIBER OPTIC LEVER DISPLACEMENT TRANSDUCERS: PRINCIPLES, IMPROVEMENTS AND APPLICATIONS.

**Author:** Kissinger, Curtis

**Source:** Advances in Instrumentation v 42 pt 3. Publ by ISA, Research Triangle Park, NC, USA p 1251-1261

**Abstract:** The recent flurry of activity in Fiber Optic Sensors has resulted in a great variety of technically sophisticated devices employing interference, polarization and wavelength modulation techniques. While all of these methods offer great promise for certain specific applications and dedicated sensors, the intensity modulated Fiber Optic Lever Displacement Transducer offers a powerful combination of simplicity, performance and low cost, which make it well suited for a wide variety of laboratory and industrial applications. 13 refs.

**1988 Title:** ON-LINE BEARING LOCALIZED DEFECTS DETECTION BY PATTERN RECOGNITION ANALYSIS.

**Author:** Li, Ching

**Source:** American Society of Mechanical Engineers, Production Engineering Division (Publication) PED v 25. Publ by ASME, New York, NY, USA p 141-152

**Abstract:** For automatic detection/diagnosis of localized defects in bearings, a pattern classification analysis technique was developed for analyzing bearing vibrations. Linear discriminant function has been established to classify a vibration signal into one of good, outer-race damaged, inner-race damaged,

and roller damaged categories according to two normalized and dimensionless features extracted by short-time signal processing techniques. It takes 20 seconds for data processing and fault diagnosis on a microprocessor based on-line implementation. Results of fault detection/diagnosis, based on the experimental data on imposed bearing defects, proved the technique to be effective and sensitive in identifying the operational state of a bearing system. (Author abstract) 14 refs.

- 1988 Title:** ON-LINE SEVERITY ASSESSMENT OF BEARING DAMAGE VIA DEFECT SENSITIVE RESONANCE IDENTIFICATION AND MATCHED FILTERING.

**Author:** Li, C.J.; Wu, S.M.

**Source:** Mechanical Systems and Signal Processing 2 3 p 291-303.

**Abstract:** A microcomputer based on-line bearing condition monitoring system was developed. Employing synchronised segmentation and parametric spectral comparisons, the system enabled on-line identification of defect sensitive resonances for an investigated bearing system at an early stage of damage. A matched filter was designed to keep track of the energy contributed by these resonances throughout the rest of bearing life. The magnitude of the energy was found to be well correlated with the development of bearing localised defects. It takes 38 sec for the identification of defect sensitive resonances and 7 sec for the matched filter to report each new assessment of bearing condition on a programmed PC-AT.

- 1988 Title:** CONDITION MONITORING OF JOURNAL BEARINGS USING VIBRATION AND TEMPERATURE ANALYSIS.

**Author:** Mathew, J.; Alfredson, R. J.

**Source:** Publ by BHRA, Cranfield, Engl p 21-33

**Abstract:** Several vibration monitoring parameters developed for the monitoring of rolling element bearing vibrations, were again evaluated for monitoring the vibration of journal bearings especially when shaft-bearing rubs occurred. Corroboratory evidence on bearing condition was also obtained using bearing shell temperature measurements. The results clearly showed that frequency based monitoring was superior in detecting partial rubs in journal bearings. Heavy rubs were equally well detected by temperature and both time and frequency based parameters. (Author abstract) 10 refs.

- 1988 Title:** MONITORING AND ANALYSIS OF ROLLING ELEMENT BEARINGS USING THE FIBER OPTIC BEARING MONITOR.

**Author:** Philips, Gerald J.

**Source:** Instrumentation in the Aerospace Industry v 33. Publ by ISA (Advances in Test Measurement v 24) (Fundamentals of Aerospace Instrumentation v 18) (Fundamentals of Test Measurement v 13), Research Triangle Park, NC, USA p 253-268

**Abstract:** Fiber optic displacement sensors are mounted inside a bearing housing to measure relative motion between a bearing and its housing. In this manner, extraneous noise and vibrations on the bearing housing are eliminated and the vibration of the bearing is clearly seen. The Fiber Optic Bearing Monitor has been developed to process bearing signals so obtained. This paper describes the FOBM and a fiber optic displacement transducer that has been recently developed, and highlights how this instrumentation can be used to give an absolute measure of bearing quality, detect and indicate the size of bearing flaws, detect lubricant contamination, and provide a measure of the load or stress on a bearing system. (Author abstract) 4 refs.

**1988 Title:** IN SITU FRICTION, WEAR AND ELECTRICAL CONTACT RESISTANCE OF PRECIOUS METAL ALLOYS.

**Author:** Pope, L. E.; Peebles, D. E.

**Source:** Tribology Transactions v 31 n 2 Apr p 202-213

**Abstract:** An in situ friction, wear and electrical contact resistance pin-on-plate system has been installed in a scanning Auger microprobe. Friction coefficients and contact resistance were measured continuously as wear progressed. The composition and topography of a wear track were measured intermittently without exposure to contaminating environments or removal of the pin from the track. Experiments were completed with control of gaseous contaminants in the ambient. For a palladium alloy pin sliding on a gold alloy plate, three stages of wear have been identified, and these are: (1) prow formation on the pin, (2) work hardening and roughening of the wear track, and (3) rider wear. The composition of the prow was essentially that of the plate material during the first two stages of wear but was a mixture of pin and plate materials during the third stage of wear. In a helium ambient high contact resistance occurred concomitantly with a transition to the third stage of wear. (Edited author abstract) 16 refs.

**1988 Title:** DIAGNOSTIC OF GRINDING PROCESS BY THE ACOUSTIC EMISSION METHOD.

**Author:** Sarshevskii, V. I.

**Source:** Soviet Engineering Research v 8 n 1 p 56-58

**Abstract:** Grinding operations on steels and alloys liable to burns and cracking are operations of abrasive machining. Attainment of effectiveness of the grinding process is connected with development of methods and means for its diagnostics. The possibility of checking the cutting properties of grinding wheels by a method based on the analysis of acoustic emission (AE) signals was investigated at the Bauman Moscow Technical School. In addition, a profilographic investigation of the grinding wheel was carried out directly on the machine tool by means of a special installation. The information content of the parameters characterizing the grinding process was evaluated. 4 Refs.

**1988 Title:** DON'T FORGET THE TIME DOMAIN IN ANALYZING BEARINGS: A CASE STUDY.

**Author:** Springer, C. W.

**Source:** Tappi Journal v 71 n 8 Aug p 190-193

**Abstract:** Defects on the inner race of rolling element bearings, such as a single, deep, fatigue spall or cracked race, may be difficult to identify from the frequency domain data alone. The digitized time domain function of the FFT spectrum analyzer is valuable in identifying such defects. The article presents copies of spectra obtained from data recorded on the bearing housing on a large spherical roller bearing, with a cracked inner race. The frequency domain and time domain data are plotted on the same spectrum for ease of reference. Spectrum No. 1 is of data recorded in the axial direction, while Spectrum No. 2 is of data recorded in the horizontal direction. All the data in the field were recorded, using a velocity transducer and a scientific-quality tape recorder, and were processed on a 400 line spectrum analyzer, with digitized time domain capabilities.

**1988 Title:** INCIPIENT BEARING FAILURE DETECTION USING THE ADAPTIVE NOISE CANCELLATION APPROACH.

**Author:** Tan, C. C.

**Source:** American Society of Mechanical Engineers, Production Engineering Division (Publication) PED v 26. Publ by ASME, New York, NY, USA p 97-107

**Abstract:** A comparative study on the detection of incipient bearing failure corrupted by severe background noise (vibration) using standard analysis techniques and the adaptive noise cancellation (ANC) technique is described in this paper. With severe background noise it is shown that the former techniques failed to detect a seeded bearing failure unless the size of the defect is considerably large. Successful detection of a seeded bearing signature is obtained with the application of the ANC to cancel/eliminate the background noise. (Author abstract) 14 refs.

**1988 Title:** SENSORS FOR MANUFACTURING.

**Author:** Tse, Ming-Kai (Ed. ); Dornfeld, D. (Ed. )

**Source:** American Society of Mechanical Engineers, Production Engineering Division (Publication) PED v 26. Publ by ASME, New York, NY, USA 227p

**Abstract:** This symposium proceedings contains 17 papers discussing applications of sensor technology in manufacturing processes. Sensors are of vital importance to productivity and quality in modern manufacturing. Unfortunately, the field of sensor research and development has been a fragmented and uncoordinated one in the past. To focus on the need for developing sensor technology into a discipline, this Symposium is organized to stimulate interest, and to provide a forum for the interchange of ideas and the latest research findings in the area. The papers in the Symposium cover a wide range of applications, including machine diagnostics, metrology,

materials characterization, and sensor calibration. The growing interest in innovative sensing techniques, the application of digital signal processing methods, and the development of rational methodologies for the design and analysis of sensing systems are reflected in the papers.

- 1987 Title:** FIBER OPTIC SENSORS.  
**Author:** Arditty, Herve J. (Ed. ); Jeunhomme, Luc B. (Ed. )  
**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 586. Publ by SPIE, Bellingham, WA, USA 261p  
**Abstract:** This conference proceedings contains 39 papers. These papers are devoted to developments in optical fiber sensor technology and the applications of fiber optic sensors. Performance results were discussed. The main subject areas are applications and systems, applications in electric machines, distributed sensors and sensor networks, signal processing and detection techniques, temperature measurements, chemical sensors, and measurement of pressure, strain, and displacements.
- 1987 Title:** AUTOMATED ACOUSTIC INTENSITY MEASUREMENTS AND THE EFFECT OF GEAR TOOTH PROFILE ON NOISE.  
**Author:** Atherton, William J.; Pintz, Adam; Lewicki, David G.  
**Source:** NASA Tech Memo 100155 10p  
**Abstract:** Acoustic intensity measurements were made at NASA Lewis Research Center on a spur gear test apparatus. The measurements were obtained with the Robotic Acoustic Intensity Measurement System developed by Cleveland State University. This system provided dense spatial positioning, and was calibrated against a high quality acoustic intensity system. The measured gear noise compared gearsets having two different tooth profiles. The tests evaluated the sound field of the different gears for two speeds and three loads. The experimental results showed that gear tooth profile had a major effect on measured noise. Load and speed were found to have an effect on noise also. (Author abstract) 7 refs.
- 1987 Title:** CHEMILUMINESCENCE: A RAPID MEANS OF SCREENING THE OXIDATIVE STABILITY OF LUBRICANTS.  
**Author:** Benov, Patricia A.; Murray, S. Frank  
**Source:** Lubrication Engineering v 43 n 5 May p 370-375  
**Abstract:** A number of compounded lubricants were evaluated, in contact with steel, to measure their chemiluminescence (CL) output as a function of temperature. The objective of this work was to determine if there is some correlation between the amount of CL and oxidation stability. The results of these tests generally ranked the oils in the same order as the ASTM D943 oxidation life tests; however, some anomalous results were obtained. In establishing repeatability, it was found that isolated tests with certain steel catalyst cups gave abnormally high CL readings, indicating unusual catalytic activity. (Edited author abstract) 20 refs.

- 1987 Title:** FIBER OPTIC SENSOR SENSITIVE TO NORMAL PRESSURE AND SHEAR STRESS.  
**Author:** Cuomo, Frank W.; Kidwell, Robert S.; Hu, Andong  
**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 661. Publ by SPIE, Bellingham, WA, USA p 234-239  
**Abstract:** A fiber optic lever sensing technique that can be used to measure normal pressure as well as shear stresses is discussed. This method uses three unequal fibers combining small size and good sensitivity. Static measurements appear to confirm the theoretical models predicted by geometrical optics and dynamic tests performed at frequencies up to 10 kHz indicate a flat response within this frequency range. These sensors are intended for use in a low speed wind tunnel environment. (Author abstract) 11 refs.
- 1987 Title:** FIBER OPTICS ACCELERATION SENSOR.  
**Author:** Daneshvar, Kasra; Davidson, J.; Esmelioglu, S.  
**Source:** Publ by IEEE, New York, NY, USA. Available from IEEE Service Cent (Cat n 87CH2401-8), Piscataway, NJ, USA p 196-199  
**Abstract:** A novel accelerometer device, the pendulus fiber accelerometer, (PFG) has been constructed and tested. The device has the potential to be rugged, sensitive, and at the same time, simple. This accelerometer has a wide dynamic range and the acceleration can be simultaneously measured in two dimensions. The operation of the PFG is based on the elastic property of the galss fiber that is used as a cantilever. The light from a laser diode or LED is guided into a fiber and focused on a silicon position sensitive detector. The acceleration causes a pendulous motion of the fiber and the displacement of the projected light from the end of the fiber on the detector is linearly proportional to the acceleration in the plane of the detector. Thus, direct linear acceleration, centripetal acceleration, or their vector sum can be analyzed. 7 refs.
- 1987 Title:** FIBER OPTIC AND LASER SENSORS IV.  
**Author:** De Paula, Ramon P. (Ed. ); Udd, Eric (Ed. )  
**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 718, Fiber Opt and Laser Sens IV, Cambridge, MA, USA, Sep 22-24 1986. Publ by SPIE, Bellingham, WA, USA, 295p  
**Abstract:** This conference proceedings contains 37 articles on developments in the field of fiber optic and laser sensors. Topics covered include: Intensity modulated fiber optic sensors; fiber optic detection and ranging (FODAR); self-referencing multiplexing technique; fiber optic magnetic sensors; chemical sensors for process control; micromachined resonant structures; fiber optic tactile array sensor; fiber optic seismometer; OTDR optical fiber sensor networks; and fiber optic immunodetectors. Technical and professional papers from this conference are indexed and abstracted with the conference code no. 1113 in the Ei Engineering Meetings (TM) database produced by Engineering Information, Inc.



- 1987 Title:** MODEL OF TOOL FRACTURE GENERATED ACOUSTIC EMISSION DURING MACHINING.  
**Author:** Diei, E. N.; Dornfeld, D. A.  
**Source:** Journal of Engineering for Industry, Transactions ASME v 109 n 3 Aug p 227-233  
**Abstract:** This paper presents details of a study of the fundamental nature of the high amplitude acoustic emission (AE) signal generated during the complete breakage of cutting tools. A quantitative model of the peak AE rms voltage, incorporating the effects of tool material and the area of the fracture surface, is proposed. The model, derived from results of Linear Elastic Fracture Mechanics, and stress wave propagation in solids, is shown to be in good agreement with results of notched carbide insert fracture during turning and face milling operations. (Author abstract) 26 refs.
- 1987 Title:** OPTICAL FIBRE VIBRATION SENSING SYSTEM.  
**Author:** Hirose, Yasuo; Abe, Takemitsu; Komai, Hiromichi; Tsuzuki, Yasuo  
**Source:** Trans Inst Electron Inf Commun Eng Sect E (Engl) v E70 n 3 Mar p 195-202  
**Abstract:** This paper describes a highly sensitive optical fiber interferometric vibration sensing system. The system is capable of measuring three dimensionally high frequency mechanical vibration amplitudes down to the order of 0. 1-0. 01 A at frequencies ranging from 10kHz up to 30MHz. The system is stabilized by a unique feedback compensation scheme against phase variations appearing in two interfering light beams due to various disturbances. Use of this scheme has realized highly sensitive semiautomatic scanning measurements. (Edited author abstract) 6 refs.
- 1987 Title:** IN-SITU SEM STUDY OF BOUNDARY LUBRICATED CONTACTS.  
**Author:** Holzhauer, W.; Ling, F.F.  
**Source:** Tribology Transactions  
**Abstract:** Low speed, steel-on-steel sliding experiments were run *in-situ* in a scanning electron microscope which was modified to allow the application of a thin film of hydrocarbon oil to the sliding surfaces. With periodic videotaping of the lubricated sliding contact and surface topography measurement, the wear process was observed and documented from initial sliding on new material, through run-in, to the eventual failure of the surfaces. It was found that grooves and finishing marks are filled with plastically deformed metal as the surfaces run-in. The loss of these lubricant retaining grooves combined with a buildup of fine wear debris leads to very fine scale surface damage at localized adhesive contacts. Continued sliding results in failure of the surfaces by a plowing/cutting mechanism.
- 1987 Title:** DIAGNOSTIC METHODS FOR POWER BEARINGS.  
**Author:** Ivanov, S. V.

**Source:** Soviet Engineering Research v 6 n 9 Sep p 24-25

**Abstract:** In mechanical engineering, in particular in transport engineering, a widespread use has been found for large bearings which run under conditions of greater loads at not very high speeds. Such bearings will be called arbitrarily 'power bearings'. The present article examines the possibility of determining the most frequently encountered defects of power bearings, such as notches, dints, pitting, cracks etc. , on the rolling tracks by the frequency spectrum of the vibratory displacements of a bearing.

**1987 Title:** SENSORS IN INDUSTRIAL METROLOGY.

**Author:** Jones, Barry E.

**Source:** Journal of Physics E: Scientific Instruments v 20 n 9 Sep, Eurosens Third Conf on Sens and Their Appl, Sep 22-24 p 1113-1126

**Abstract:** Industrial metrology is concerned with sensors to measure movement of machine tool parts and monitor tool wear and the dimensions of artefacts in machining centres, sensors for robots in flexible manufacturing systems, sensors to gauge mating parts for selective assembly or allowing for interchangeability, and sensors for inspection and testing of assembled or part-assembled products. Sensors are required in all the widely differing manufacturing fields. In general, the dimensional, shape and physical properties of functional parts need to be inspected. This paper reviews the subject and emphasises significant advances, from the use of resonant sensor systems, edge-sensing profilers and methods of laser scanning, to acoustic emission techniques, imaging systems, and the scanning tunnelling microscope. A bibliography, a listing of recent relevant conference proceedings, and an extensive list of references are provided. (Edited author abstract) Refs.

**1987 Title:** PREDICTION OF MACHINERY DAMAGE BY THE ANALYSIS OF WEAR PARTICLES AND BY VIBRATION ANALYSIS (VORAUSSAGE VON MASCHINENSCHADEN DURCH ANALYSEN VON VERSCHLEISSPARTIKELN SOWIE DURCH SCHWINGUNGSANALYSEN).

**Author:** Kuoppala, R.; Kuusisto, E. **Corporate Source:** Technical Research Cent, Espoo, Finl

**Source:** Maschinenschaden v 60 n 1 p 11-15

**Abstract:** Two methods are particularly suitable for the earliest possible determination of damage to rotating machinery, such as gears: Analysis of the wear particles in the lubricating oil (size distribution, shape, and chemical composition) by the separation in a magnetic field over an inclined glass plate, and optical assessment, in association with the use of scanning electron microscopes, makes it possible to make a satisfactory determination of the time when the destructive wear was initiated. When vibration analysis is used, the vibration amplitudes are investigated and the logarithmic frequency spectra converted by Fourier transform into cepstrum form, which is particularly useful in providing the periodicity needed for the diagnosis.

Both methods are suitable for condition monitoring and preventive maintenance. (Edited author abstract) 9 refs. In German.

**1987 Title:** DIAGNOSTICS OF MACHINERY VIBRATIONS.

**Author:** Lim, M. K.

**Source:** v 2. Publ by Noise Control Foundation, Poughkeepsie, NY, USA p 1201-1206

**Abstract:** In this study, various common machinery faults were simulated on two different rotor models. The vibration patterns or signatures in both the time domain and frequency domain for each particular fault are collected for analysis to establish the diagnosis criteria of each type of fault. The faults simulated on the rotor sets are broadly classified as unbalance, oil whirl/oil whip, preload, rubbing, bearing defects and misalignment. Analysis of the orbital plots, spectrum plots and cascade plots revealed the essential characteristics of each type. In order to improve the analysis capability as well as to automate the process, automatic trend warning and analysis can be carried out by combining vibration monitoring and high speed vibration analysis with a micro-computer.

**1987 Title:** IMPLEMENTATION OF FIBER OPTIC TECHNOLOGY IN NAVAL COMBATANTS.

**Author:** Morais, Robert M.

**Source:** Marine Technology v 24 n 1 Jan p 59-71

**Abstract:** This paper provides a summary of activities and developments that directly impacted the implementation of fiber optics on naval combatants. The paper concludes that the benefits are clear, that the technology has matured, and that implementation as a system element in ship design and construction is accelerating. The paper also includes a short tutorial on the basic elements of a fiber optic link as well as the advantages, disadvantages, and applications of fiber optics. (Author abstract) 6 refs.

**1987 Title:** MEASUREMENT OF OIL FILM STATE USING TWO KINDS OF ELECTRICAL CIRCUIT.

**Author:** Nakashima, Katuhiro; Takafuji, Kazuki

**Source:** v 2. Publ by Elsevier Science Publ Co, New York, NY, USA p 615-620

**Abstract:** The electrical resistance method is adopted frequently as a simple mean for measuring a state of the oil film at the lubricated portion, but its measuring range is restricted within thin oil film and it is difficult to examine film thickness quantitatively. In this paper the electrical circuit detectable thicker oil film in addition to usual one and the evaluating value of a state of the oil film are investigated with considering to use it at plane contact where forms thicker oil film in comparison with point or line contact. However there exists some factors such as load and sliding velocity which prevent the quantitative measurement. (Edited author abstract) 3 refs.

- 1987 Title:** IN SITU DETECTING OF HOT-TEARING IN SOLIDIFYING Al-Cu AND Al-Si BINARY ALLOY CASTINGS BY MEANS OF AE METHOD.  
**Author:** Ohtaki, Mitsuhiro; Naguchi, Tetsuya; Uto, Hideyuki; Honma, Umewo; Oya, Shigeo  
**Source:** Keikinzoku/Journal of Japan Institute of Light Metals v 37 n 3 Mar 1987 p 207-213  
**Abstract:** AE signals detected in the final freezing zone of Al-2-20% Cu and Al-1-7% castings solidifying in the I-beam type hot tearing mold are discussed on the basis of the formation process of hot tearing. Two types of AE signals are detected in the later stage of solidification. One is the continuous type corresponding with the solidification end and the formation of microcracks or shrinkage cavities at grain interfaces. The other is the burst type corresponding with the propagation of microcracks. On-line monitoring of hot tearing is possible. (Edited author abstract) 8 refs. In Japanese.
- 1987 Title:** IN SITU FRICTION, WEAR AND ELECTRICAL CONTACT RESISTANCE OF PRECIOUS METAL ALLOYS.  
**Author:** Pope, L.E.; Peebles, D.E.  
**Source:** Tribology Transactions 31 2 p 202-213  
**Abstract:** An in situ friction, wear and electrical contact resistance pin-on-plate system has been installed in a scanning Auger microprobe. Friction coefficients and contact resistance were measured continuously as wear progressed. The composition and topography of a wear track were measured intermittently without exposure to contaminating environments or removal of the pin from the track. Experiments were completed with control of gaseous contaminants in the ambient. For a palladium alloy pin (ASTM B540) sliding on a gold alloy plate (ASTM B541), three stages of wear have been identified, and these are: (1) prow formation on the pin, (2) work hardening and roughening of the wear track, and (3) rider wear. The composition of the prow was essentially that of plate material during the first two stages of wear but was a mixture of pin and plate materials during the third stage of wear. In a helium ambient high contact resistance occurred concomitantly with a transition to the third stage of wear
- 1987 Title:** ROLE OF WEAR PARTICLE ANALYSIS IN THIN-FILM LUBRICATION.  
**Author:** Roylance, B. J.; Vaughan, D. A.  
**Source:** Publ by Butterworths, London, Engl and Boston, MA, USA p 285-292  
**Abstract:** The role of wear particle analysis is evaluated in relation to a rolling-sliding line contact. The results of analysis using ferrography in conjunction with Quantimet indicate that the quantity and size distribution of ferrous free-metal particles deposited on the ferrogram slide correlates well with the performance characteristics measured while undergoing test operation in a twin-disc machine at two different slide-roll conditions. Morphological and compositional aspects are also examined and discussed in

terms of the contribution of particle measurement and analysis to increasing our understanding of wear in thin film operation. (Author abstract) 14 refs.

- 1987 Title:** EFFECT OF COOLANT CONTAMINATION IN LUBRICATING OIL ON JOURNAL BEARING LOAD CAPACITY - A RADIOMETRIC EVALUATION.

**Author:** Schneider, Eric W.; Blossfeld, Daniel H.; DeHart, Arnold O.

**Source:** Lubrication Engineering v 43 n 10 Oct p 800-805

**Abstract:** Radioisotopic tracer techniques were used to study the relationship between journal bearing load capacity and engine coolant contamination (ethylene glycol and water) in lubricating oil. Hydrodynamic bearing load capacity was determined by applying a unidirectional load to a radioactive bearing located in a test fixture. The onset of bearing wear, determined by the detection of radioactive wear particles in the lubricant, was used to indicate the load at which fluid-film breakdown occurs. Results show that coolant contamination levels less than 15 percent by volume have little effect on the hydrodynamic load capacity of a journal bearing. At higher contamination levels (between 20 and 40 percent), bearing load capacity drops rapidly as the continuous phase of the emulsion changes from an oil base to a coolant base. Measurements of emulsion viscosity at both low and high shear rates were found to be highly dependent on the specific method of emulsion preparation, and could not be used to predict journal bearing load capacity. (Author abstract) 12 refs.

- 1987 Title:** TOOL MONITORING WITH ACOUSTIC EMISSION INDUSTRIAL RESULTS AND FUTURE PROSPECTS.

**Author:** Souquet, P.; Gsib, N.; Deschamps, M.; Roget, J.; Tanguy, J. C.

**Source:** CIRP Annals v 36 n 1. Publ by Technische Rundschau, Berne, Switz p 57-60

**Abstract:** Tool breakage has been successfully detected by Acoustic Emission in turning, milling and drilling. A new autoadaptive system has been developed and successfully tested in industrial conditions. Tool wear monitoring was also investigated in turning, milling, drilling and high speed milling. The cutting speed and the depth of cut are very important for the Acoustic Emission level. Acoustic Emission contains an information on the cutting processes and particularly on the tool wear but presently no general relationship between any Acoustic Emission parameter and tool wear can have been derived even if in some cases, Acoustic Emission changes is strongly related to tool modifications. (Author abstract) 5 refs. In French.

- 1987 Title:** APPLYING MODERN TECHNIQUES TO TRADITIONAL SENSORS.

**Author:** Tenney, Albert S.

**Source:** Chilton's I&CS (Instruments & Control Systems) v 60 n 8 Aug p 21-23

**Abstract:** Two approaches are being used today to improve process measurements. One involves so-called smart sensors, which improve the interpretation of a sensor's signal by providing communication and/or computational capabilities right at the sensor (see article beginning on p 25). The second approach-which is the subject of this article-seeks to improve the actual sensing function through superior material and design technology. Two technologies having considerable impact on sensor development are thin film/solid state manufacturing processes and fiber optics. This article details these technologies as they are being applied to temperature, pressure, humidity, and specific ion sensors.

**1987 Title:** GENERAL REVIEW OF DEVELOPMENTS IN ACOUSTIC EMISSION METHODS.

**Author:** Tonolini, F.; Sala, A.; Villa, G.

**Source:** International Journal of Pressure Vessels and Piping v 28 n 1-5 p 179-201

**Abstract:** The ability of Acoustic Emission (AE) to detect, with high sensitivity, the mechanical energy released by flow evolution, may be used to get information about crack growth, onset of new defects and their dynamic behavior, during the first hydrotest and later requalification testing of nuclear components and continuous monitoring of power plant operation. In this review, the most recent developments in AE for nuclear component monitoring are examined. Suitable AE equipment for logging high rates of AE data, real-time source location and parametric analysis are discussed. (Edited author abstract) 88 refs.

**1987 Title:** FIBER OPTICS IN MACHINE VISION.

**Author:** Vinarub, Edmund J.; Flom, Stuart

**Source:** Photonics Spectra v 21 n 6 Jun p 57-61

**Abstract:** Machine vision may be viewed as the most important development required to advance the state of the art of industrial robots. In addition, machine vision has had, and will continue to have, a profound effect on the concepts and methodology of the approaches now taken for on-line quality control monitoring or automated inspection. Illumination by fiber optics will play an increasingly important role in providing cost-effective responses to the needs of users of vision systems. The main topics are the promise of fiber, coupling to fiber, coherent imaging, and image quality.

**1987 Title:** NON-CONTACT SURFACE FLAW DETECTION BY FIBER OPTIC REFLECTION SENSORS.

**Author:** Waegli, P.; Huber, R.; Morger, E.

**Source:** Proceedings of SPIE - The International Society for Optical Engineering v 665. Publ by SPIE, Bellingham, WA, USA p 53-58

**Abstract:** Optical sensors can be used for the non-contact control of mechanical parameters (e. g. surface quality) in fully automated production and assembly systems. The applicability of such optical sensor systems to a

particular production line mainly depends on the detection limits (i. e. which size of scratches can be detected on a particular surface). A simple dimensionless number,  $D$ , was found describing the detection limit ( $D > 1$ ). The important parameters within  $D$  are: the reflectivity of both, the unperturbed surface and the defect, the area of the surface flaw and the noise generated by the statistical surface structure. The detection limits for different common flaws on various characteristic surfaces often present in the metal processing industry will be discussed together with examples of fiber optic sensor designs. (Author abstract) 11 refs.

- 1987 Title:** LASER VIBRATION DEPOT INSPECTION OF GEAR BOXES.  
**Author:** Watts, Robert J.; Rice, David A.; Neun, John A.  
**Source:** SAE Technical Paper Series Publ by SAE, Warrendale, PA, USA 14p  
**Abstract:** A program was initiated to develop a transmission and transfer case production inspection test system. The test system was to be designed for both final acceptance inspection and preoverhaul testing to identify internal component quality and wear levels. The system design included automatic evaluation of characteristic vibration frequencies, both from the gear meshes and bearings, and the transient vibration response measured during gear shift operation. A noncontact sensing approach, utilizing laser vibration measurement, was selected for use by the inspection system. The equipment nomenclature was, therefore, defined as the Laser Vibration Sensor Inspection Test System (LVS/ITS). Phase I of the LVS/ITS development program successfully verified the feasibility of, and defined dual technologies for, gear box diagnostic/prognostic test logic and the Laser Vibration Inspection System design specifications. (Edited author abstract)
- 1986 Title:** ON THE THERMAL ASPECT OF FRETTING WEAR-TEMPERATURE MEASUREMENT IN THE SUBSURFACE LAYER.  
**Author:** Attia, M. H.; Ko, P. L.  
**Source:** Wear v 111 n 4 Oct 1 p 363-376  
**Abstract:** In fretting wear, the kinetics of the oxide film formation, as well as the microstructure and the mechanical properties of the subsurface layer, depend significantly on the temperature field produced in the fretted zone. Information reported in the open literature indicates contradicting values for the temperature produced at the interface. In the present study, an experimental method for direct measurement of the temperature profile in the subsurface layer has, therefore, been developed and verified. This method overcomes the limitations and the uncertainties inherent in methods of measurement used before. An error analysis indicated that the temperature gradient can be measured within PLUS OR MINUS 2.5%. The extent of the temperature measurement zone has been estimated by the theory of thermal constriction resistance and found to be in good agreement with some available experimental data. (Author abstract) 17 refs.

- 1986 Title:** CORRELATION BETWEEN SCIENTIFIC STUDIES AND PRACTICE IN TRIBOLOGY.  
**Author:** Barwell, F. T.  
**Source:** Soviet Journal of Friction and Wear (English translation of Trenie i Iznos) v 7 n 5 p 7-14  
**Abstract:** We examine the status of practical applications of tribology in engineering. Primary attention is devoted to the need for extensive development of means for diagnosing, monitoring, and processing tribotechnical information. The wear mechanisms are examined with account for surface morphology and the possibility of analysis of the process on the basis of the surface wear particles. (Author abstract) 31 refs.
- 1986 Title:** MANUFACTURING PROCESS MONITORING AND ANALYSIS USING ACOUSTIC EMISSION.  
**Author:** Dornfeld, David A.  
**Source:** Special Supplement to Journal of Acoustic Emission p 123-126  
**Abstract:** Metalworking operations compose a large portion of industrial activity in the United States every year. With metal cutting costs alone at approximately \$125 billion each year. Acoustic emission analysis has been proven effective as a sensing methodology for machine tool condition monitoring in research at the University of California-Berkeley. This paper reviews earlier work on machining monitoring and analysis and documents the research done recently on wear and fracture detection for multiple insert machining operations (milling), chip form detection, analysis of the milling process, and tool fracture and wear modeling based on analysis of acoustic emission (AE) generated during machining. 9 refs.
- 1986 Title:** IN-PROCESS DETECTION OF GRINDING CRACKS BY THE USE OF ACOUSTIC EMISSIONS.  
**Author:** Eda, Hiroshi; Kakino, Yoshiaki; Fujiwara, Akihiko; Nakajima, Masayuki; Ueno, Hideo; Kishi, Kozo;  
**Source:** Bull Japan Soc Precis Eng. V 19 N 3 Sep. 1985 P 181-186  
**Abstract:** Grinding tests have been performed under abusive conditions to hardened steel, with the aim of detecting grinding cracks. In-process acoustic emission signals, which were detected during grinding, have been analyzed and compared with the signal produced before the grinding cracks were formed. Acoustic emissions between 600-800 kHz are detected when grinding cracks are not formed. By utilizing this relationship, it becomes possible to detect grinding cracks in process. (Edited author abstract) 4 refs.
- 1986 Title:** ACOUSTIC EMISSION COMES OF AGE.  
**Author:** Fowler, Timothy J.  
**Source:** Publ by SPI, New York, NY, USA Sess 16. B, 9p  
**Abstract:** Acoustic emission has developed into one of the most important nondestructive tests for monitoring the structural integrity of composites, and the method is widely used for quality control and periodic in-service



inspection of fiber reinforced plastic equipment. The technology has found extensive use in the laboratory, where it can provide valuable insights into material behavior. In addition, a number of companies have used acoustic emission as a design aid for composite components such as pressure vessels and piping. In 1981 the Society of the Plastics Industry published a recommended practice for testing tanks/vessels, and in 1983 published a companion document for testing piping systems. These recommended practices have led to simplified, standardized methods of test. The cost and complexity of test equipment has also been reduced dramatically, and the test has become relatively inexpensive. It is anticipated that the recently completed ASTM Standards E 1067 for tanks/vessels and F914 for aerial manlifts, together with ASME Section V Article 11 will contribute to the growing field use of acoustic emission. The presentation reviews the technology of acoustic emission, its use for testing composites, recent advances in defect signature characterization, its application to field testing, and the use of acoustic emission as a research, development, and design tool. (Edited author abstract) 30 refs.

- 1986 Title:** ON-LINE ACOUSTIC EMISSION MONITORING OF NUCLEAR REACTOR SYSTEMS - STATUS AND FUTURE.

**Author:** Hutton, P. H.

**Source:** Special Supplement to Journal of Acoustic Emission p 74-76

**Abstract:** Development of acoustic emission (AE) technology for on-line monitoring of nuclear reactors has been going on to one degree or another for the past 20 years. The feasibility of performing on-line monitoring to detect flaw growth in reactor pressure boundaries has been demonstrated. There are a few well defined technology elements that require further attention, but limited application appears to be near. (Edited author abstract) 4 refs.

- 1986 Title:** FIBRE OPTIC SENSORS.

**Author:** Jackson, D. A.; Jones, J. D. C.

**Source:** Optica Acta v 33 n 12 Dec p 1469-1503

**Abstract:** In this paper we review the current state of development of fibre optic sensors, including those based on both monomode and multimode technology. For monomode techniques, a general formalism describing their optical characteristics is developed; electronic processing techniques and noise performance are also considered. Examples of their application in the measurement of temperature, pressure, strain, flow, rotation and magnetic field are described. Extrinsic devices such as velocimeters and vibrometers, and applications in holography, are also discussed. Multimode techniques based on intensity and wavelength modulation and quantum effects are considered, and their application to a wide range of measurands is reviewed. (Author abstract) 108 refs.

- 1986 Title:** CHEMICAL ANALYSIS WITH FIBER OPTICS.

**Author:** Krohn, David A.

**Source:** Publ by ISA, Research Triangle Park, NC, USA p 43-50

**Abstract:** Fiber optics is a broad-based technology which can be used to sense both physical and chemical phenomena. Most fiber optics research has centered around high precision position sensing. However, techniques are evolving which allow fiber optics to be used for qualitative and quantitative chemical analysis. There are four basic design approaches which can be used. The first is fluorescence which involves having ultraviolet light impinge directly upon the target material which, in turn, emits a characteristic fluorescence. The second and third approaches use absorption or scattering of transmitted light which is characteristic of the element being sensed. The fourth approach involves refractive index changes associated with the chemical being analyzed. This paper discusses the basic concepts involved and the state of the art technology. (Edited author abstract) 7 refs.

**1986 Title:** SENSING CHEMICALS WITH OPTICAL FIBRES.

**Author:** Narayanaswamy

**Source:** Control and Instrumentation v 18 n 3 Mar p 35-36

**Abstract:** Optical fibre chemical sensing devices are based on a simple concept of using optically conducting fibre interfaced to a small transducer (consisting of chemical reagent systems) that varies its optical property with the chemical parameter under investigation. This technology can produce a series of sensors that can have many advantages to process control. The author outlines progress to date.

**1986 Title:** DEVELOPMENT OF HIGH FIDELITY ACOUSTIC EMISSION TRANSDUCERS.

**Author:** Proctor, Thomas M.; Breckenridge, Franklin R.; Eitzen, Donald G.

**Source:** Publ by ASM, Metals Park, OH, USA p 329-337

**Abstract:** The development of a transducer which measures the normal displacement of a 'point' on a surface is reviewed. This transducer has sufficient bandwidth so that it can measure, with high sensitivity, the dynamic surface motion due to an AE event. Certain improvements in the design are discussed. Captured waveforms from the best model of the transducer are compared with theoretical elasticity predictions of surface displacement. (Edited author abstract) 11 refs.

**1986 Title:** IN-PROCESS TOOL WEAR SENSING BY ACOUSTIC EMISSION.

**Author:** Tse, Ming-Kai; Briggs, John C.

**Source:** v 1. Publ by Int Committee on Nondestructive Testing, Columbus, OH, USA p 70-77

**Abstract:** This paper demonstrates the feasibility of using acoustic emission to detect tool wear. Tool wear tests were performed using 1026 and 8620 steel and carbide tools on a lathe. It was found that acoustic emission increases with both flank and crater wear. It was also determined that built-up-edge formation generates transient acoustic emission. In light of these experimental findings, the existing theories on acoustic emission in

machining are critically reviewed, and a more realistic picture on the mechanisms for AE generation is also presented. (Author abstract) 6 refs.

**1986 Title: AC IMPEDANCE MEASUREMENTS OF THE RESISTANCE AND CAPACITANCE OF LUBRICANTS.**

**Author:** Wang, S.S.; Maheswari, S.P.; Tung, S.C.

**Source:** ASLE Transactions v 30 4 p 436-443.

**Abstract:** An AC impedance technique in combination with a thin-film (12  $\mu\text{m}$ ) cell was employed to separately measure the electrical resistance and capacitance of electrode-lubricant interfaces and bulk lubricant layers. In this study, three different additives were investigated by measuring the AC impedance spectrum of each additive mixed separately with a commercially available mineral oil. These additives were oleic acid, N-oleyl-1,3 diaminopropane (fatty amine), and mixed alkyl acid orthophosphate (acid phosphate). For lubricants containing 2 mass percent of an acid phosphate or fatty amine, the capacitance of the electrode-lubricant interface,  $C_i$ , and the capacitance and resistance of the bulk lubricant layer  $C_o$  and  $R_o$ , respectively, were evaluated separately from the AC impedance spectra. The lower limit of the resistance of the electrode-lubricant interface,  $R_i$ , was also estimated. For additives, such as oleic acid, which physically adsorbs on the electrodes, the resistance and capacitance of the electrode-lubricant interface and the bulk lubricant layer could not be measured separately.

**1986 Title: NEW INSTRUMENT FOR MEASURING CONTACT RESISTANCE DEVELOPED FOR STUDYING ELECTRICAL CONTACT PHENOMENA.**

**Author:** Watanabe, Yoshitada

**Source:** Wear v 112 n 1 Oct 15 p 1-15

**Abstract:** A new experimental apparatus for measuring the electrical contact resistance is described. This apparatus is essentially a conventional balance, modified for the examination of electrical contact resistance changes of silver and some other metal specimens due to increases and decreases in load and current. (Edited author abstract) 5 refs.

**1985 Title: FREQUENCY DOMAIN METHODS FOR MONITORING THE CONDITION OF ROLLING ELEMENT BEARINGS.**

**Author:** Alfredson, R. J.; Mathew, J.

**Source:** Mechanical Engineering Transactions - Institution of Engineers, Australia v ME 10 n 2 July p 108-112

**Abstract:** Tests were carried out on seven self aligning ball bearings to evaluate a number of narrow band spectral methods, based on vibration measurement, for monitoring bearing condition. Failure was relatively easy to detect where there was significant impulsiveness present in the acceleration signal. The early stages of failure however were generally most consistently detected using the matched filter root mean square method. This

approach was more sensitive than the time domain methods. (Author abstract) 15 refs.

- 1985 Title:** ADVANCED MASS SPECTROMETRY OF LUBRICANTS.  
**Author:** Campana, J.E.; Freas, R.B.  
**Source:** ASLE Transactions v 29 2 p 235-245.  
**Abstract:** Several developments have been made in mass spectrometry during the last few years. One of the most significant developments, fast-atom bombardment mass spectrometry, has tremendous potential for the characterization of lubricants. The technique is described, and examples of its use for the direct, rapid, and semiquantitative characterization of synthetic base oils and additives in lubricants are given.
- 1985 Title:** REAL-TIME HOLOGRAPHIC INTERFEROMETRY THROUGH FIBRE OPTICS.  
**Author:** Dudderar, T.D.; Gilbert, J.A.  
**Source:** Journal of Physics and Engineering: Scientific Instruments v 18 p 39-43.  
**Abstract:** Stable, high frequency holographic interference fringes have been recorded on objects illuminated and viewed through fibre optics in real time using a system of singlemode fibre optic illuminators, a multimode fibre optic image bundle and a lensless 'instant' holocamera. This development has great potential for applications in the full-field remote measurement of surface displacements and/or deformations as they occur.
- 1985 Title:** NON-CONTACT SURFACE VIBRATION ANALYSIS USING A MONOMODE FIBRE OPTIC INTERFEROMETER INCORPORATING AN OPEN AIR PATH.  
**Author:** Lewin, A. C.; Kersey, A. D.; Jackson, D. A.  
**Source:** Journal of Physics E: Scientific Instruments v 18 n 7 Jul p 604-608  
**Abstract:** A very high sensitivity non-contacting vibration analysis system based upon a monomode fiber optic Mach Zehnder interferometer incorporating an open air path is described. The systems was operated in both a closed loop limited tracking range ( $> 10^{+5}$ ) homodyne mode and an effectively infinite tracking range novel pseudo-heterodyne mode. For periodic signals, amplitude detection sensitivities of approximately  $2 \times 10^{-11}$  m at 10 Hz to  $5 \times 10^{-11}$  m at 10 kHz have been demonstrated for both modes of operation. (Author abstract) 14 refs.
- 1984 Title:** NONCONTACTING ELECTROMAGNETIC ACOUSTIC TRANSDUCER FOR SEPARATELY DETECTING LONGITUDINAL AND TRANSVERSE WAVES IN METALS AND ITS APPLICATION TO AE SENSOR.  
**Author:** Shimizu, Hiroshi; Watanabe, Hiroshi; Sato, Michio  
**Source:** Japanese Journal of Applied Physics, Supplement v 23 suppl 23-1 p 116-118

**Abstract:** A new type of noncontacting electromagnetic acoustic transducer (EMAT) which is capable of detecting and generating longitudinal and transverse ultrasonic waves independently is developed. The EMAT has large conversion losses, but its conversion loss characteristics are very flat over the wide frequency range. Applicability of the EMAT to an AE sensor is also investigated experimentally. (Author abstract) 4 refs.

- 1984 Title:** OVERVIEW OF RESEARCH AT MIT IN THE QUANTITATIVE NONDESTRUCTIVE EVALUATION OF FIBER COMPOSITE MATERIALS AND STRUCTURES.

**Author:** Williams, James H. Jr.; Lee, Samson S.

**Source:** Tech Pap Soc Manuf Eng EM84-103, 12p

**Abstract:** An overview of the state of the art results on the ultrasonic, acoustic emission (AE), thermographic and acoustic-ultrasonic nondestructive evaluation (NDE) of composite materials based upon the authors' research in the Composite Materials and Nondestructive Evaluation Laboratory at the Massachusetts Institute of Technology is presented. The use of ultrasonic attenuation, 'AE (parameter) delay', liquid crystals thermography and 'stress wave factor' in structural integrity monitoring is discussed. The research emphasis is beyond the basic flaw detection approach of NDE as it is highly coupled with flaw significance characterizations in order to establish quantitative measures for accept/reject criteria. Also the NDE of flawed composites, without overt defects, is emphasized. Some of the capabilities of computer-aided NDE (CANDE) currently being developed are described. (Author abstract) 37 refs.

- 1983 Title:** RAMAN SPECTRA OF LUBRICANTS IN ELASTOHYDRODYNAMIC ENTRAPMENTS.

**Author:** Gardiner, D.J.; Baird, E.; Gorvin, A.C.; Marshall, W.E.

**Source:** Wear v 91 p 111-114.

**Abstract:** We report the initial results of a novel Raman spectroscopy method for studying lubricant characteristics in a simulated elastohydrodynamic contact. The method uses a Raman microscope [1] which allows spectra to be obtained from a small volume (about 0.1 nl) of lubricant entrapped in the elastic deformation formed when a loaded glass plate falls onto a lubricated steel ball. The existence of such entrapments is well established following the early work of Dowson and Jones [2] and several theoretical models of the normal approach of two surfaces have succeeded in predicting the resultant film thickness and lubricant viscosity during approach [3,4]. The work described here was undertaken to obtain direct pressure measurements from an entrapped fluid at equilibrium after the initial impact.

- 1982 Title:** A VISIBLE LASER INTERFEROMETER FOR AIR BEARING SEPARATION MEASUREMENT TO SUBMICRON ACCURACY.

**Author:** Nigam, A.

**Source:** Transactions of the ASME v 104 p 60.

**Abstract:** Hydrodynamic lubrication problems can be investigated using a visible laser interferometer, as presented here, to obtain both steady-state and dynamic film thickness characteristics. The special case of a self-acting air bearing slider system used in present day computer peripheral equipment is investigated. Measurement accuracies of better than  $0.005\text{ }\mu\text{m}$  can be achieved for both steady state and dynamic measurements. This technique should be especially valuable for low spacing, self-acting lubrication problems and can surpass the accuracies of presently used interferometric, capacitive, and inductive methods. A mathematical treatment of the optical interference phenomena as applicable to a hydrodynamic lubrication film is developed.. Experimental results are presented and discussed.

**1979 Title:** FOURIER EMISSION INFRARED MICROSPECTROPHOTOMETER FOR SURFACE ANALYSIS - I. APPLICATION TO LUBRICATION PROBLEMS.

**Author:** Lauer, J.L.; King, V.W.

**Source:** Infrared Physics v 19 p 395-412.

**Abstract:** A Beckman-RIIC FS-720 far-infrared interferometer was converted into an emission microspectrophotometer for surface analysis. To cover the mid-infrared as well as the far-infrared the Mylar beamsplitter was made replaceable by a germanium-coated salt plate, and the Moiré fringe counting system used to locate the moveable Michelson mirror was improved to read  $0.5\text{ }\mu\text{m}$  of mirror displacement. Digital electronics and a dedicated minicomputer were installed for data collection and processing. The most critical element for the recording of weak emission spectra from small areas was, however, a reflecting microscope objective and phase-locked signal detection with simultaneous referencing to a blackbody source.

An application of the technique to lubrication problems is shown.

**1975 Title:** FERROGRAPHY - AN ADVANCED DESIGN AID FOR THE 80'S.

**Author:** Scott, D.; Seifert, W.W.; Westcott, V.C.

**Source:** Wear v 34 p 251-260.

**Abstract:** With the sophisticated machinery of the 80's it will be essential to effect design improvements during prototype testing to eliminate both maintenance and failure in service. Ferrography allows the *in situ* condition of inaccessible mechanisms to be monitored and thus enables design changes and their assessment to be completed prior to the use of the machinery in service; lubricant deterioration can also be diagnosed and necessary remedial measures effected.

The equipment used and the investigational techniques developed are described. Specific applications and the significant results obtained are illustrated from the work of the authors and their associates over a wide field.

**1972 Title:** A METHOD FOR THE STUDY OF WEAR PARTICLES IN LUBRICATING OIL.

**Author:** Seifert, W.W.; Westcott, V.C.

**Source:** Wear v 21 p 27-42.

**Abstract:** A new instrument has been developed which is capable of precipitating magnetic particles ranging in size from a few micrometers down to approximately 20 nm from liquids such as lubricating oils. With this instrument, designated a Ferrograph, particles are arranged according to size on a transparent substrate. The particles recovered from lubricating oil exhibit an amazing complexity and range of sizes and types. The density of the deposit may be measured optically, or the deposited particles may be examined with an optical or an electron microscope. Some of the particles recovered from the lubricating oil of a typical machine are known to be associated with abrasive wear and others the result of adhesive wear. Corrosion products are also observed.

The instrument is of use in research on lubricants, in the study of wear mechanisms, and as a device for the detection of the onset of abnormal wear as might occur in the course of a ball bearing failure in a jet engine.

## **APPENDIX**

### **An Analysis of On-Line Machinery Sensing**



## **Technical Background**

One of the objectives of this project is to advance the use of on-line sensors in machinery as means for monitoring and responding to changes in machine performance because of lubricant deterioration or other malfunctions. During the last fifty years, significant progress has been made in our understanding of the behavior of lubricants. Advances in fluid-film, squeeze-film, and elastohydrodynamic (EHD) theory and analysis, coupled with a better comprehension of lubricant chemistry, boundary lubrication and wear have made it possible to predict bearing life with some measure of certainty. Wear begins as soon as an engine is placed in service. However, under normal operating conditions it is a slow, gradual process after the surfaces have been run-in. With proper maintenance, very long life should be obtained, but such predictions presuppose ideal operating conditions. Unforeseen changes in those conditions can have a significant effect on lubricant behavior. Chemical changes in the lubricant, as a result of high temperatures or contamination, are one major factor in determining the performance of the system that is being lubricated.

## **Current Methods for Evaluating Changes in Lubricants**

The determination of the condition of an engine and its lubricant, as a result of field service, is a well-established procedure. Several articles have been published by Texaco on evaluating used engine oils in general [1], and on marine diesel engine lubricants [2-4]. Vail [5] described procedures for compressor oil analysis. The problems of oil analysis for monitoring hydraulic oil systems were described by Poley [6]. While each application has its own particular requirements, most of the procedures are common to all of them. Standard bench test methods have been developed [7] and specifications have been prepared showing acceptable variations. The primary causes of impaired effectiveness are contamination from outside sources and degradation by chemical changes. Contaminants include: water, either fresh or seawater, dirt as abrasive particles (sand, silicates and metal oxides), and fuel residues such as soot and oxides (from engine blow-by). Wear particles can also act as abrasive contaminants.

Water contamination is generally the result of leaking seals and gaskets. It can also be caused by cracked engine blocks or heads. Condensation of water from the air is common in engines that run infrequently or in very humid environments. Water can cause rusting of ferrous surfaces and it may also react with sulfur compounds produced by fuel combustion and blow-by to form sulfuric acid. This acid will promote corrosive wear of the piston rings and cylinder walls, thus reducing engine life between overhauls. Water can also promote oil oxidation and could form oil in water emulsions that would impair lubrication.

Another very important cause of wear and reduced engine life is contamination by abrasive particles from external sources. Defective air cleaners, engines which have been partially disassembled and left without adequate protection, and containers of oils or greases which have been opened and left uncovered are all likely sources of contamination. Dirty dispensing equipment also contributes to the problem.

Dilution of the oil by fuel leakage or excessive blow-by will affect oil viscosity and reduce load-carrying capacity. The combustion of rich fuel-air mixtures can produce soot which, in the presence of water, may form a black sludge.

Even if there was no external contamination, engine oils would still deteriorate in time. Oxidation at high temperatures would result in increased viscosity and, ultimately, varnish or sludge formation. The presence of wear particles also tends to catalyze oil reactions. Summing up, Table 1 [1] lists some of the causes of oil deterioration and the test methods that are normally used to detect problems. It should be emphasized that the interpretation of these tests often requires certain skills and technical background. Table 2 [4] presents a typical check list which relates the results of the crankcase oil analysis to engine condition or operation.

Most of these evaluations require that a characteristic sample of lubricant be taken from the machinery and delivered to a laboratory for analysis. Under normal conditions, the results might not be available for days.

### **Sensors for Machinery**

The concept of using sensors to monitor and control machinery is well established. The original driving force was aerospace applications because weight and size were so critical. In the last decade, advances have been rapid, primarily because more engineers have learned to use integrated circuits and have found them to be both economical and reliable, once they reached the stage of mass production. From automobiles to kitchen appliances, sensors are now playing a major role in both manufacturing and product applications.

Table 3 lists a number of different types of sensors that are of interest in this study. The majority of these have been widely used in laboratories for years. In many cases, the basic concept of the sensor has not changed, but it has been shrunk down to the barest essential size and embedded (integrated) into a system.

The literature search that was done for this report has uncovered a wealth of information on the fabrication techniques and methods of using certain types of sensors. To advance the state-of-art, the first step would be to decide what to monitor in the system. Would it be bearing temperatures or a change in the physical or chemical properties of the lubricant? Perhaps it would be an increase in the ratio of large to small wear particles in the oil, or a change in the acoustic output of the bearings. Once that has been established, backup sensors should be selected to provide added confirmation of problems by monitoring related operating characteristics.

The emphasis of this discussion is on practical, lubricated machinery, the kind of equipment that can be reasonably expected to last for many years as long as it is properly maintained. The sensors are intended to serve as warning devices when marginal conditions develop.

### **Monitoring Engine Condition by Wear Particle Analysis**

During the mid 60's, the military services established the Spectrometric Oil Analysis Program (SOAP) to monitor the buildup in wear particle concentration (as a

**TABLE 1 (From Ref. 1)**

**BASIC USED OIL TESTS  
For  
Gasoline Engines**

<b>Diesel Engines</b>	<b>Gasoline Engines</b>	<b>Gas Engines</b>
Appearance and Odor	Appearance and Odor	Appearance and Odor
Water	Water	Water
Viscosity	Viscosity	Viscosity
	Dilution	
Flash Point		
Insolubles		
Neutralization or Base Number	Neutralization or Base Number	
		Differential Infrared
Ash Content	Ash Content	Ash Content
Spectrographic Analysis	Spectrographic Analysis	Spectrographic Analysis

TABLE 2

## RELATION OF USED CRANKCASE OIL ANALYSIS TO ENGINE CONDITION OR OPERATION

Test Result	Probable Cause	Contributing Engine Condition or Operation
Water Contamination	1. Condensation	Low temperature operation Low cooling jacket temperature Inadequate crankcase ventilation Excessive engine idling Short periods of intermittent service
	2. High Blowby	Ring Belt Area Worn rings or liners Stuck or broken rings Exhaust system restrictions
	3. Coolant Leakage	Leaking head gasket Improperly torqued cylinder head Defective or blown gasket Leaking seals on wet-side liners Defective seal Improper installation Cracked block or cylinder head
	4. Improper operation of centrifuge	In marine service water-washing will introduce water if centrifuge is not operated properly.
Viscosity Reduction	1. Use of lower viscosity product	—
	2. Fuel Dilution	Gasoline Engines Rich carburetion Malfunctioning choke Improper adjustment Poor Combustion Worn or stuck rings Poor valve performance Ignition problems Fouled spark plugs Cross firing Loose wiring or faulty ignition cables Faulty condenser or coil Improper timing Low cooling jacket temperature Excessive engine idling Cracked fuel pump diaphragm Diesel Engines Overfueling Restricted fuel return line Oversize injectors Poor Combustion Poor injector spray pattern Dribbling injectors Restricted air supply or exhaust system Worn rings and liners Ring sticking or breakage Cracked or broken fuel line fittings
Viscosity Increase	1. Use of a higher viscosity product	—
	2. Contamination	Water Fuel Soot — discussed under Insolubles
	3. Degradation	High Temperature operation Peak power output Inadequate cooling Lean operation Over-extended oil drains

## RELATION OF USED CRANKCASE OIL ANALYSIS TO ENGINE CONDITION OR OPERATION

Test Result	Probable Cause	Contributing Engine Condition or Operation
Insolubles Contamination	1. Fuel Soot	Rich operation Overfueling Restricted air intake Defective injectors Poor spray pattern Dribbling nozzles Worn rings or liners, stuck rings Inadequate air filter maintenance Air leaks in intake system Generally related to quantity of ingested dirt Inadequate oil filter maintenance High temperature operation Overextended oil drains Oil Pumping Worn bearings, valves, guides & rings High crankcase oil level
Neutralization Number Slow or Moderate rise Rapid rise	Effects of normal service 1. Contamination 2. Oil oxidation	— Fuel blowby products Excessive operating temperatures Overextended service period
Strong Acids Present	Heavy fuel blowby	Low cylinder wall temperatures Inadequate water washing during purification
Total Base Number Slow Reduction Rapid Reduction	Effects of normal service Heavy fuel blowby	—
Differential Infrared Increased Absorption at 5.8-5.9 microns Slow Rise Rapid Rise	Effects of Normal Service Oil oxidation	— Overextended service High temperature oxidation High piston and cylinder temperatures Engine hot spots High bulk oil temperature
Increased Absorption at 6.2 microns	Nitrogen fixation	Lean fuel-air ratios Improper spark timing Faulty crankcase ventilation Excessive blowby Engine overload
Reduced Ash Content	1. Use of low ash product 2. Additive loss	— Degradation due to severe service Water contamination and sludging Use of active clay filters that remove additives
Increased Ash Content	1. Use of higher-ash product 2. Contamination	— Fuel lead blowby products Ingested dirt Engine metal wear Cylinder oil residues

**TABLE 3**

**TYPICAL SENSORS USED IN THE LABORATORY**

- 
1. Temperature sensors - thermocouples, thermistors, and infrared detectors.
  2. Position sensors - eddy current or capacitance probes, LVDT sensors, lasers and ultrasonic range detectors.
  3. Vibration sensors - accelerometers, strain gages, capacitance probes.
  4. Speed sensors - magnetic pickups, optical encoders, tachometers.
  5. Force or pressure - piezoelectric or piezorestrictive sensors.
  6. Metal-to-metal contact detectors - electrical resistance or voltage drop.
  7. Chemical sensors - dielectric constant.
  8. Optical sensors - densitometers, IR, UV fluorescence, spectroscopy, photoconductivity cells, photodiodes.
  9. Acoustic emission - ultrasonic and sonic detectors.
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function of operating hours) in the lubricants used for aircraft gas turbine engines [8]. The instruments used for the analyses were atomic emission (AE) and atomic absorption (AA) spectrometers. Currently, most of the work is being done with the rotating-disc electrode atomic emission spectrometry (RDE-AES). This program has been reasonably successful in reducing premature failures. In a recent (1989) Conference on Conditioning Monitoring [9], Centers and Price presented a discussion of Air Force experience with this method and possible directions for future work. There are certain drawbacks to the use of the spectrographic method of analysis. The technique is limited to small wear particle sizes and it cannot distinguish between soluble metal compounds and metallic wear debris.

To resolve these difficulties, ferrography was introduced in the 1970's as a more versatile method for monitoring wear [10]. Using this technique, the ferrous particles are separated out of the oil by a combination of gravity and magnetic forces. With the aid of an optical densitometer, ferrography can monitor the relationship between the normal size wear particles, which are always present in operating machinery, and the large wear particles that indicate the onset of marginal operation. As was the case with the SOAP program, it is necessary to draw off oil samples and send them to a laboratory for analysis.

It has been reported that both spectroscopy and ferrography have been useful for detecting problems. In the 1989 Conference on Conditioning Monitoring [9], approximately half of the papers that were presented were on these two methods. Each has its advocates; however, both require expensive instrumentation and skilled laboratory personnel. Samples must be withdrawn and sent to a laboratory for analysis. Periodic evaluations of wear debris by both ferrography and spectroscopy are now being done for various types of industrial machinery, particularly for heavy construction equipment.

It should also be noted that serious efforts are being made to convert both of these techniques to on-line systems. With Air Force support, Pieper and Taylor [11] designed and built an on-line X-ray spectroscopy system to monitor the circulating lubricant in a TF41 aircraft engine. Their report describes the construction and preliminary results obtained with this monitor. The system uses X-ray fluorescence to detect both ferrous and nonferrous metal particles on a continuous basis while the engine is running. The sensor is engine mounted and contains a radio-active X-ray source (Curium-244), a flow cell to direct oil flow across an X-ray permeable beryllium window, a proportional counter, and an X-ray detector with preamplifier and amplifier electronics.

The data acquisition electronics is mounted on the air frame and contains a microprocessor-based system for inputting pulses from the sensor, classifying and counting them according to their energy bands, and analyzing the data and outputting metal concentrations to the engine monitoring system.

The report describes how many problems were encountered and overcome. One particular problem was to ensure that a uniform oil flow was being passed under the X-ray permeable window. The authors described the use of a "spreader" to accomplish this.

Evaluations have also been made [12-14] using on-line, direct reading ferrography to ratio large to small wear particles in bench test, circulating oil systems. Centers [12] had trouble with the instrument readout during start-up at room ambient temperatures (20° to 25°C). By preheating the sensor with a heat lamp and insulating the connecting tube and sensor, the problem was solved. Holzhauer [13] found that when a large amount of wear debris flooded the sensor, the analyzer would read high and constant values and would not return to normal operation until the sensor was flushed with solvent. Iivonen and Aho [14] found good correlation between the normal direct reading ferrograph and the on-line monitor. However, oil flow rates and the method used to clean the sampling tubes had significant effects on the readings of the on-line monitor. Kuoppala et al. [15] used ferrography, coupled with vibration analysis, for condition monitoring and preventive maintenance.

All of the techniques that were evaluated showed varying degrees of promise, but each also has certain drawbacks.

### **Spectroscopy Techniques**

The use of infrared techniques to study oil film temperatures as well as chemical changes of lubricants in dynamic systems has produced much useful information about the behavior of lubricants in EHD contacts. Lauer and Ahn [16] used both optical and infrared spectroscopy to study EHD lubricated contacts. The purpose of that work was to evaluate the effect of lubricant additives on fuel economy. A typical petroleum base stock was blended with selected additives so that all of the test fluids had a viscosity of 7.1 centistokes at 100°C, regardless of the types of additives. Initially, a steel ball rotating against a sapphire window was used to obtain the traction values and an infrared detector, to measure temperature. Then the authors set up a mock journal bearing using a polished stainless steel shaft 12.7 mm in diameter and a conforming (but fixed) partial arc bearing pad which was made of an infrared transparent material (probably sapphire). Film thicknesses under elastohydrodynamic conditions were measured for all of the test fluids. It was concluded that lubricant additives can change the EHD film thickness and traction, even though the bulk viscosity is the same.

Cann and Spikes [17] studied the behavior of lubricants in an operating EHD contact, using FTIR microreflection absorption spectroscopy. The EHD contact was formed by a rotating steel ball immersed in a controlled temperature oil bath and loaded against a stationary sapphire or diamond flat. The FTIR microscope was focused in the EHD contact region and reflected infrared radiation was collected by the optics of the microscope for analysis by the IR detector. Evaluations included: the direct determination of the pressure conditions experienced by the lubricants in the contact zone, the formation of antiwear films by phosphorus additives and the study of the alignment of molecules in the contact.

These spectroscopy methods require the same kind of setup as the X-ray fluorescence technique that is being developed by Pieper and Taylor [11]. They all require a window. The X-ray fluorescence method uses a beryllium window which is permeable to X-rays, while the FTIR method requires a sapphire or diamond window. These are transparent to infrared radiation. It may also be necessary to control the flow past the window when using the infrared method. All of these infrared techniques are

observing the EHD contact between a ball and a flat. It is not known if the method will work as well if thicker films of lubricant are being observed. The "spreader" technique used by Pieper and Taylor [11] might be effective here.

### **Chemical Sensors**

Chemical changes in the lubricant are of major concern in this context. They not only result in corrosion and wear, they also affect critical physical properties such as viscosity. It has been well-documented that the deterioration of both oils and greases manifests itself in the following ways:

- Production of free radicals which form hydroperoxides and peroxides as a result of initial oxidation reactions between the hot oil and the ambient air.
- Gradual loss of oxidation inhibitor, which is consumed in the initial oxidation steps, and the rapid breakdown of the oil when the inhibitor concentration drops below a certain level.
- An increase in the total acid number (TAN) and viscosity with time at temperature. For overbased detergent oils, the initial change would be a decrease in the total base number (TBN).
- A loss of volatiles which also results in an increase in viscosity.
- Corrosion of metals as a result of the formation of organic acids.
- Deposits of insoluble sludge and varnish.

The formation of hydroperoxides in lubricating oils is being studied using chemiluminescence techniques [18]. Free radicals, formed during the initial oxidation of hydrocarbons, decay to a lower energy state with the emission of a photon. Sensitive photomultiplier tubes can then be used to detect and count these photons.

This technique is useful for research studies on reaction rates, but the equipment and environmental control needed is both expensive and delicate.

As far as the rest of the indicators of lubricant breakdown are concerned, there is general agreement that the changes in lubricant properties all signal that the lubricants are approaching the end of their useful lives. Figure 1, which was taken from [19] illustrates the relationship that has been shown to exist between antioxidant life and changes in fluid properties such as viscosity, acid number and rate of gas evolution.

Kaufman [20] and Dominguez et al. [21] evaluated an electrical method, cyclic voltammetry, which could be used to monitor the effective life of the aromatic amines that are used as oxidation inhibitors in many types of lubricants. Microelectrodes, immersed in solutions of the oils, provide measurements of half-wave potentials against an Ag/AgCl reference electrode. This method is based on the premise that once the antioxidant is consumed, lubricant life is essentially over.

Other techniques for detecting lubricant life are:



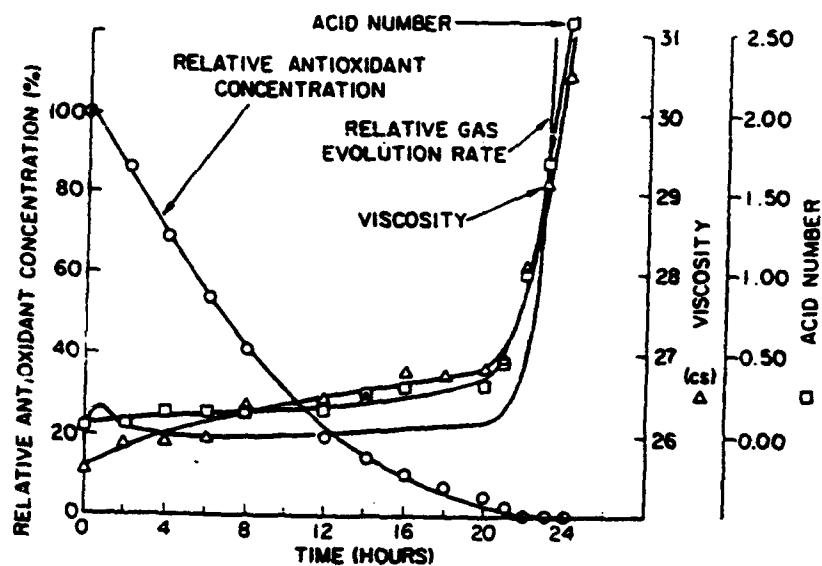


Figure 1 Example of Correlation of Onset of Gas Evolution and Viscosity and Acid Number Increases During Oxidation. The lubricant was pentaerythritol tetrahexanoate. Oxidation temperature was 200°C. In this case, degradative oxidation commenced at approximately 20 hours. (Taken from Ref.19.)

- 1) Using dielectric constant measurements to monitor changes in the oil [22]. This was done with a commercial device that was developed for automotive lubricants. It senses changes in the used oil, relative to fresh oil.

Saloka and Meitzler [23] also described an engine-mounted capacitive sensor to monitor changes in the dielectric constant of the engine oil. The sensing element is a small, air-gap capacitor mounted in a spacer ring that fits between the oil filter and the engine block. The circuitry is embedded in the same spacer ring. As long as the antioxidants were active, the readings showed a slight decrease, but when they were exhausted, the dielectric constant increased at a steady rate.

- 2) Centers and Smith [24] described the use of a proprietary Complete Oil Breakdown Rate Analyzer (COBRA) which senses certain electrochemical changes in the oil as it is oxidatively degraded. Laboratory tests showed promise; however poor correlation was observed between the COBRA results and total acid number and viscosity changes for a number of field test samples. This was attributed to differences in engine breather design and it was concluded that a new correlation must be established for each application. Additional data on COBRA is given in [25].

Electronic gas sensors, which are used to monitor the presence of flammable vapors, have also attracted attention as means for detecting the condition of lubricants. A suitable solid-state metal oxide semiconductor that can detect oxidizable gases, will react with the volatile hydrocarbons that are given off by the hot oil. The conductivity of the semiconductor increases significantly with increasing concentration of vapors and provides a clear signal of their presence. Ravner and Wohltjen [19] and Bolster and Wohltjen [26] have shown that this approach has merit. They demonstrated that an increase in gas evolution also marked the point at which the antioxidant was practically depleted and the acid number and viscosity were increasing rapidly.

There is considerable commercial interest in the improvement of this type of sensor [27-29] because they are being widely used in the home. New regulations for the use of carbon monoxide detectors will provide more inducement for improved versions. An added inducement is the fact that the sensor occupies only a few cubic millimeters of volume, so it is already close to the desired size range.

### **Temperature Sensors**

Unusual increases in temperature can be very sensitive indicators of problems in machinery. For example, there are very practical limits to the temperatures that babbitted bearings can tolerate. Exceeding these limits can result in plastic flow and wiping as well as deterioration of any lubricant that is in close proximity to the bearing surface.

Thermocouples and infrared detectors appear to offer the best characteristics for temperature measurements as far as reliability and space requirements are concerned. For example, Kannel et al. [30] used a "bisignal" transducer (in the form of a vapor-deposited sandwich) for simultaneously determining contact zone pressure and

temperature of rolling/sliding steel cylinders. The transducer had a layer of  $\text{Al}_2\text{O}_3$  about  $1\text{ }\mu\text{m}$  thick applied by rf sputtering. Over this was a vapor-deposited manganin layer about  $0.1\text{ }\mu\text{m}$  thick, then another layer of sputtered  $\text{Al}_2\text{O}_3$  and finally a vapor-deposited layer of titanium about  $0.1\text{ }\mu\text{m}$  thick.

Safa et al. [31] also described thin film transducers which were used for measuring pressure in EHD contacts. By changing the configuration of the transducer, they were also able to measure pressure and temperature or pressure and film thickness simultaneously.

Tian et al. [32] made a thin film thermocouple of vapor-deposited copper and nickel sandwiched between thin films of a hard, nonconducting alumina ceramic. The thermocouple was about  $2\text{ }\mu\text{m}$  thick and occupied a surface area of about  $80\text{ }\mu\text{m} \times 300\text{ }\mu\text{m}$ . A finite element model which could be used to compare predicted and measured temperatures was also described.

Hamel [33] described the use of a thin film thermopile detector for noncontact temperature sensing. De Frutos and Jimenez [34] evaluated lead titanate ceramics for pyroelectric sensors. They found that the response to thermal stimulus depended on which surface was exposed to the infrared radiation. Based on their findings, they proposed an optimal lead titanate ceramic composition to be used for the sensor. Bonne and Havey [35] described a multi-purpose microbridge flow control sensor that is in production at Honeywell. That microsensor is apparently only designed for use with gases as the process fluid, but it suggests avenues of approach to liquid multisensors.

Finally, Schaefer [36] discussed both fiber-optic and quartz temperature sensors for use in industrial applications. He reviewed the basic technology and the pros and cons of these sensors.

From the results of the literature search on measuring temperatures, it appears that a variety of approaches are feasible. The selection will likely be based on how readily the selected sensor can be embedded in the multisensor package.

### **Acoustic Emission**

Sounds, such as those caused by vibrations in a machine, tell much about its operating condition. For this reason, the largest number of citations found in the literature search were on the subject of acoustic emission. One of the major advantages of using sound as a means of sensing machine performance is the possibility of obtaining a "sound signature" on a new piece of equipment. Then, as the machine progresses through the run-in phase and into steady-state operation, the signatures can be recorded to compare with the original or a run-in trace. Sudden changes in spectra after run-in would indicate potential problems which can often be assigned to certain components.

The equipment required for sensing, recording and analyzing data is very diverse. For example, sliding metal to metal contacts generate ultrasonic noise [37] which can be detected by the same kind of hand-held instrument that is used to detect gas leaks. The advantage of this type of equipment is that it can pinpoint the location

where the noise is being generated. Karlberg et al, [38] described plant experience with an ultrasonic bearing monitoring system.

Much more sophisticated equipment is also being used to obtain vibration patterns or signals in both the time domain [39] and frequency domain [40,41]. For example, Li [42] described a pattern classification analysis technique which was based on vibrational signals from: 1) a good rolling contact bearing 2) an outer-race and an inner-race damaged bearing and a roller damaged bearing. Two normalized and dimensionless features were extracted from these bearings by short-time signal processing techniques. Using this method, twenty seconds is required to process data and make a fault diagnosis with a microprocessor. Lim [43] has presented a similar approach for rotor models.

A variety of sensors can be used for detection including: microphones, accelerometers, ultrasonic detectors, an electromagnetic vibration sensing system, a fiber optic bearing monitor [44], etc.

In this context, the goal of the vibration or sonic emission is not to aim for the most sophisticated detector, but rather to use a simple and rugged sensor to provide a suitable warning, and to include one or two optional techniques for verification of the warning.

### **Other Types of Sensors**

As shown in Table 3, there are many other types of sensors that are (or could be) used online to detect operating conditions. Selection of one type over another will depend on a number of factors such as: the method used to transmit data, the reliability of the chosen technique and the operating environment. In every case, redundancy should be achieved by using two or three sensors to monitor performance. These may be different types of sensors rather than duplicates. Eventually, the signals from the sensors will be transmitted through a network to microprocessors which receive, process, and respond to these bits of information.

The types of sensors used in automotive and other transportation applications should be carefully reviewed. Those sensors are most likely to be rugged and able to tolerate harsh environmental conditions. They will also be very cost effective.

One very important problem which was not addressed very well in the literature is the need for detecting the presence of liquid water. There are humidity sensors available, but no sensor was found which could be used to monitor the amount of liquid water in oil. This is an important gap in sensor technology which must be addressed. Carduner et al. [45] described the use of a near infrared (NIR) absorption sensor which was used to provide a continuous online analysis of the amount of methanol in a methanol-gasoline fuel mixture. This technique should be evaluated to see if it can be used to monitor the quantity of liquid water in oil. The analysis is based on the absorbance of light at specific wavelengths in the near infrared spectral region from 650 to 2500 nanometers. This includes chemical bonds of C-H, N-H, or O-H. As the authors point out, a sensor being used to monitor a single component, such as water (O-H), should only have to scan a very limited number of wavelengths of light to detect its

**TABLE 3**

**TYPICAL SENSORS USED IN THE LABORATORY**

- 
1. Temperature sensors - thermocouples, thermistors, and infrared detectors.
  2. Position sensors - eddy current or capacitance probes, LVDT sensors, lasers and ultrasonic range detectors.
  3. Vibration sensors - accelerometers, strain gages, capacitance probes.
  4. Speed sensors - magnetic pickups, optical encoders, tachometers.
  5. Force or pressure - piezoelectric or piezorestrictive sensors.
  6. Metal-to-metal contact detectors - electrical resistance or voltage drop.
  7. Chemical sensors - dielectric constant.
  8. Optical sensors - densitometers, IR, UV fluorescence, spectroscopy, photoconductivity cells, photodiodes.
  9. Acoustic emission - ultrasonic and sonic detectors.
-

presence and concentration. Limiting the spectral range required will simplify the detector. The final selection of the desired range of wavelengths will have to be made by examining the extended range spectrum.

It should be noted that the type of lubricant (petroleum oils vs synthetic oils such as polyesters) may complicate the analysis. In addition, if the water formed an emulsion with the oil, it would create a cloudy mixture. The authors found that cloudiness caused a small shift in the wavelength determination. This point would have to be rechecked carefully. Figures 2a and 2b, taken from [45] show a schematic and a photograph of the second generation prototype of the NIR flex fuel sensor.

The dielectric-effect, flexible fuel sensors described by Meitzler and Saloka [46] may also provide means for detecting water by changes in dielectric constant.

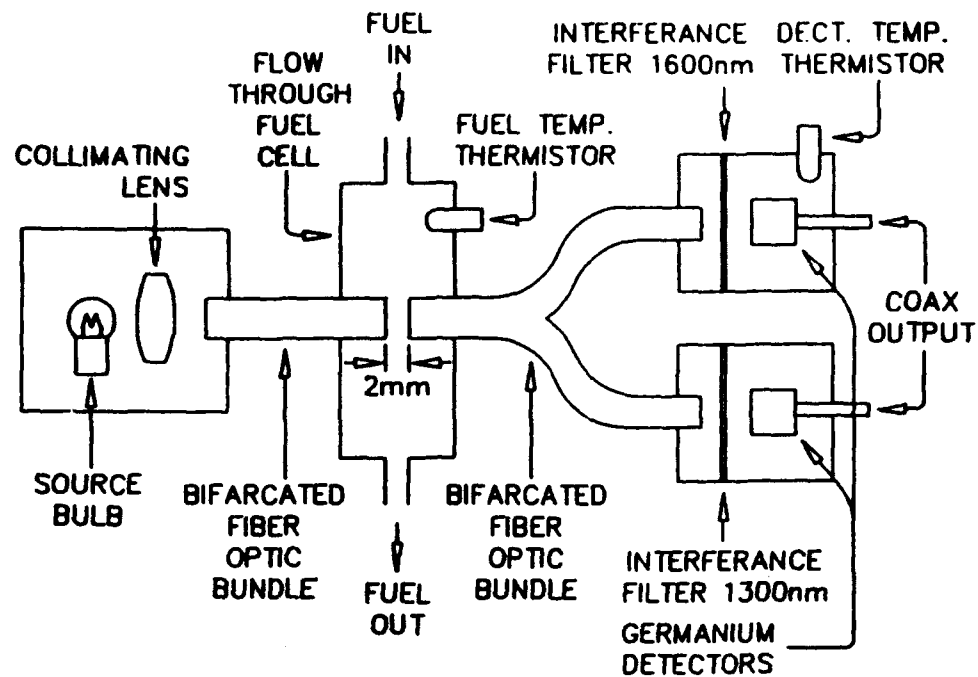
### **Micromachining**

This term, micromachining, is used to describe the fabrication techniques that are commonly used to make integrated circuits. However, as shown in Table 4, none of the operations bears any resemblance to conventional machining processes. To date, most of the emphasis has been placed on silicon because of its favorable cost, availability, and its physical and chemical properties. References [47] and [48] are up-to-date descriptions of the state of the art for micromachining silicon. It is important to bear in mind that years of effort have been devoted to the development of the techniques used to process silicon. Although other semiconductors, especially gallium arsenide (GaAs) are faster, have higher temperature capabilities and desirable characteristics such as the ability to lase in the infrared range, the techniques needed to make integrated circuits with this semiconductor are still being developed. It has not been possible to integrate a light source with Si-based structures, but with GaAs, both optical and mechanical structures are feasible.

Atoms in the GaAs crystal have nuclear charges and electron distributions that are significantly different than those atoms in a silicon crystal. One step toward improved fabrication was described by Ukita et al. [49] who showed that when aluminum is used to heavily dope selected areas of GaAs, the AlGaAs is not etched. This allows the processor to shape and undercut the GaAs by reactive dry etching and selective wet etching. Zhang and MacDonald [50] describe the fabrication of submicron, single crystal actuators of GaAs.

### **Conclusions**

The results of the open literature search are encouraging. There is no shortage of sensor concepts to monitor different aspects of machinery operation. The technology for integrating the outputs of these sensors is also available and improving steadily. There is, however, a need to remember that the lubricant problems which must be monitored are the same problems discussed in Refs. [1-4]. These include: changes in viscosity, acid number, volatility, presence of water, etc. The problems have not changed; it is the way that they are monitored and the ways the signals are being used that are different.



**Figure 2a** Block diagram of the prototype NIR based methanol sensor.



**Figure 2b** Photograph of the prototype sensor prior to mounting in a flex fuel vehicle. The electronics module is placed inside of the passenger compartment.

**TABLE 4**

**TECHNOLOGIES USED IN SILICON MICROMACHINING**

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Chemical wet etching  
Photolithography  
Thermal growth of silicon oxide  
Chemical vapor deposition  
Electron beam and sputter deposition  
Plasma etching  
Electrochemical etching  
Diffusion and implantation  
Epitaxial deposition  
Anodic bonding  
Silicon-to-silicon fusion bonding

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Combinations of these technologies are used for fabricating silicon transducers. Taken from [48].



Based on the findings reported in the literature [19-21], consumption of the oxidation inhibitor marks the point at which the lubricant begins to degrade at a rapid rate. Once the inhibitor concentration has fallen below a certain level, then the acid number, viscosity, and volatility of the oil all start to increase [Figure 1]. This suggests that the use of a dielectric sensor (e.g., [22,23,46]), backed up by an electronic gas sensor [19,26,27], would provide confirming signals of the onset of oil degradation. Preliminary results [23] have shown that the dielectric constant decreases slowly during the useful life of the lubricant. When the concentration of the oxidation inhibitor has fallen below the level where it can protect the oil, then the dielectric constant begins to increase rapidly. This is accompanied by an increase in the evolution of light hydrocarbon vapors and these vapors will activate the electronic gas sensor, providing a confirming signal of lubricant breakdown.

There is also a need for a sensor to detect the presence of water in the oil. Consideration should be given to the use of the near infrared spectrometer [45] to monitor the oil. This technique should be effective in detecting water, and may also be useful for sensing fuel dilution or antifreeze contamination in the oil.

In addition to the sensors being used to monitor the oil, other sensors could be mounted at selected locations on the machinery to detect operating characteristics such as bearing temperatures, acoustic emission, and vibration characteristics of the mechanical components.

The evaluation of wear debris, particularly by determining the ratio of large particles to small particles, deserves more effort. This ratio is a very sensitive indicator of problems. If a better way of cleaning and flushing the sensor could be developed, then the on-line ferrograph would be a very useful monitor that would supplement the information from the other sensors.

In advancing the state-of-art, there will be a need to maintain a continuous review of the current literature. What was a barrier yesterday may be an opportunity today. The SAE publications, especially their annual Sensors and Actuators are very useful in describing activities in the automotive field. IEEE also publishes practical articles in some of their journals, e.g., "Circuits and Devices," and "Transactions on Electron Devices." Most ASME articles on this subject are presented in special Divisional Publications such as the Product Engrg. (PED) or Fluids Engrg. (FED) Divisions. The Journal "Sensors and Actuators," published by Elsevier, is more research oriented and international in scope. STLE has also published a number of practical papers on specific problems. New journals, such as Journal of Micromechanics and Microengineering, were started in 1992.

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